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Management practices for maintenance of native prairie in Iowa

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MANAGEMENT PRACTICES FOR MAINTENANCE OF NATIVE PRAIRIE IN IOWA

by

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INTRODUCTION

Before the advent of the white man, five-sixths of Iowa was covered with virgin prairie. The intervention of man and his subsequent cultivation of the highly productive prairie soil has all but eliminated this vast area of waving grasses and the brightly colored flowers of various socies of broadleaf plants. According to a 25 year plan prepared by the Iowa State Conservation Commission in 1933, two tracts of prairie were purchased; the Hayden prairie in 1945 and the Kalsow prairie in 1948. These were secured in order to save, under the control of the state, a living museum of the characteristic native prairie landscape with its grasses, wild flowers, and fauna, and to make available a field laboratory where scientific observations and experiments could be conducted.

In 1949 an advisory committee of the Iowa Academy of Science initiated a program for the management of the two prairie reserves (49). During the interim necessary for the vegetation to recover from excessive mowing and intermittent grazing, it was considered advisable to obtain quantitative and qualitative information on the vegetation, soils, and climate of the tracts which would include: an inventory of the plant species, identification of the plant communities, soil type maps, weather record summaries, and a determination of the condition of the vegetation and soils of the tracts as to degree of disturbance from past use. These initial studies (72) were completed in 1953.

Results of these studies indicated that recovery of the Hayden prairie, under complete protection, had passed its highest rate by 1953 chiefly because of the accumulation of a quantity of litter and duff which was slightly greater than the annual yield of vegetation. It was decided that management experiments involving the removal of litter and duff from areas of moderate size, could be safely initiated in 1954 and that these areas could be expanded later if there were no deleterious effects on vegetation and soil.

In order to develop an effective, long-time management program, it is necessary to know to what degree management practices such as complete protection, mowing, burning, or grazing will alter the environmental factors of the area. This information is basic to the separation of the direct effects of management practices on individual plants of the communities from the indirect effects of the practices through altered environmental factors.

The purpose of the research reported herein was to determine the immediate and cummulative effects of different management practices on the vegetation and soils of mesic prairie in order to recommend a management program for the native prairie reserves in Iowa. It is presumed that the presentation and interpretation of data on the interactions among management practices, environmental factors, and growth of the component plants of the prairie community may have some application value in the field of grassland management.

LITERATURE REVIEW

The Prairie Association

The grasslands of central North America extend from Manitoba and Saskatchewan to Texas and Mexico. On the basis of physiognomy, floristics, and environmental factors, Clements (23) classified this extensive plant community as the grassland formation of central North America. The prairie association extends along the eastern border of the formation from Manitoba through eastern Dakotas, Nebraska, and Kansas and central Oklahoma and Texas to Mexico (1, 23, 86, 87, 102). Its contact on the east is with the oak-hickory association of the deciduous forest formation of eastern North America (87, 101, 102) and on the west with the mixed prairie association (1, 115).

The width of the prairie association is much greater in the central states because of a wedge-like prairie peninsula which extends eastward through southern Minnesota, northern Missouri, almost the entire state of Iowa, southeastern Wisconsin, central Illinois, and into Indiana with further outliers in Ohio and Kentucky (87, 101, 110, 115).

The actual extent of the prairie has been the subject of many articles in recent years (26, 82, 90, 91, 101, 109, 112, 116, 117). Transeau (101) has presented perhaps one of the most convincing papers on this subject in which he correlated the vegetation of the area with climatic factors and other data to support the above mentioned eastward extent of the prairie. There has also been much speculation as to whether the prairie peninsula is true climax or subclimax (70, 90, 91, 101, 109, 114, 116, 117). Moyer (72) has reviewed most of the recent literature concerning this subject in his work on the ecology of prairie in Iowa, and concluded that the upland prairie, except in the northeastern and southeastern parts of the state, is climax under present soil and climatic conditions.

Investigations of the prairie in Iowa began at an early date. In 1911 Shimek (90) brought together the results of 20 years of study in a paper entitled, "The Prairie". He gave an extensive review of pertinent literature, along with accumulated data on environmental factors such as topography, soils, evaporation, and other climatic factors. Two important papers (115, 117) give an exact and detailed description of the prairie. The former paper outlines climate and soils of the prairie, discusses six types of grassland communities with major and minor grasses and their principal forbs, the relative importance of each species, height growth and physiological activity, and five seasonal aspects. However, the prairie association described in this paper is not delimited. The latter paper deals with the mechanical and chemical analysis of the soils, precipitation, water content of soil, temperature of air and soil, humidity, wind and evaporation of the prairie. Steiger's paper on the structure of prairie vegetation (94) is an approach to a sociological account of the prairie. Weaver (108) and Weaver and Fitzpatrick (114) discussed the role of individual species in prairie communities. H. S. Conard (26) listed the various communities of prairie in Iowa as presented by Hendrickson (50) and gave the dominant and subdominant grasses and forbs of each. The more recent papers of Moyer (72) and Aikman and Thorne (5) present ecological and taxonomic descriptions of some existing native prairie tracts in Iowa.

Almost one-half of the area of the prairie peninsula lies within the boundaries of the state of Iowa (101). The state occupies the broad central portion of the triangle which has its base to the west in eastern Nebraska and northeastern Kansas and its apex in Indiana. The soils of this triangular prairie peninsula were classified by Marbut (67) as soils of the northern prairies. This area and the southern prairie soils area were defined and mapped entirely on the basis of the character of the soils. According to Marbut, the prairie soils are grassland soils but were developed under a high rainfall (67). Typical prairie soils are not podzolic, although development seems to have taken place under the influence of a rainfall high enough to have podzolized them. In fact, it may be said that the soil is in the earliest stages of podzolic development (67).

In support of the thesis of the stability of the prairie over most of the area of Iowa, Transeau (101) emphasized the contrast in climatic factors of the prairie peninsula with the climatic factors of the adjacent deciduous forest on the north, south, and east. The chief factors considered were efficiency of the water supply (precipitation-evaporation ratio), midsummer relative humidity, seasonal distribution of rainfall, and degree of climatic variability. On the basis of these factors, he considered the climate of the prairie peninsula to be more favorable to the growth of prairie than of the deciduous forest. On the map of the climatic provinces and of the plant growth regions of the United States (102), as well as on the soils may by Marbut (67), the location of the prairie peninsula and its distinctive habitat are in general agreement with Transeau.

Within the prairie association, there is a gradual change in habitat and plant community structure from west to east. The greatest expanse of the association in which this change is evident is from the westward extent of the prairie association in eastern Nebraska to the eastward end of the prairie peninsula in Indiana (2, 49, 60, 101, 114). The prairie is generally more mesic in Iowa and eastward than on its western border, a few miles west of Lincoln, Nebraska (2, 114). On the extensive upland soil types of Iowa which were developed under prairie vegetation (79), the chief dominants on the basis of frequence x abundance are Andropogon scoparius[1], Stipa spartea, and Sporobolus heterolepis (5, 49, 72, 114). On the same basis, Andropogon gerardi is a dominant of the upland prairie in much of the area and Bouteloua curtipendula in many locations especially in the western part of the state. On the basis of frequence alone, both Bouteloua curtipendula and Koeleria cristata would be considered dominants. Sporobolus heterolepis increases in abundance on some dry sites, on thin soils, and under excessive mowing (5, 72).

The undrained and poorly drained soils of the state, such as Webster and Clyde, and some alluval soils (79) were developed under lowland prairie. This subclimax prairie corresponds to the wet meadow stage of the hydrosere (23). Under conditions of adequate drainage, the upland prairie will replace the subclimax prairie. The chief factor affecting the occurrence of the five dominants in the lowland prairie is degree of soil aeration. Listed in order from wet sites with poor aeration to relatively drier lowland sites, the dominants are Spartina pectinata, Panicum virgatum, Elymus canadensis, Sorghastrum nutans, and Andropogon gerardi (5, 49, 72, 114). In very wet, unaerated areas, Spartina pectinata may be the only dominant. Elymus canadensis is the least abundant dominant of the lowland prairie, followed by

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[1]Nomenclature in this thesis follows Fernald (39).

Sorghastrum nutans (5, 72). As stated above, *Andropogon gerardi* is also a dominant in more mesic upland prairies as is *Sorghastrum nutans*, although less frequent and abundant (5, 49).

Management Practices

The object of range or pasture management is usually thought of as obtaining the maximum forage yields consistent with perpetuation of the vegetation (97, p. 133). To obtain either of these objectives, it is important to know how each management too, or combination of tools such as mowing, grazing, and burning, will affect the vegetation, soil micro-climate, and other factors of the environment (2, 22, 93).

Grazing and mowing

Weaver and Hansen (116) grouped prairie species into three categories (1) those that decrease or disappear under grazing, (2) those that increase under grazing, and (3) those that invade pastures. They listed *Andropogon gerardi*, *A. scoparius*, *Sorghastrum nutans*, *Spartina pectinate*, *Elymus canadensis*, *Panicum virgatum*, *Stipa spartea*, *Koeleria cristata*, and *Sporobolus heterolepis* as key prairie grasses that decrease under grazing. They also listed *Amorpha canescens*, *Petalostemon purpureus*, *Aneomone cylindrica*, *Aster laevis*, *A. sericeus*, *Coreopsis palmata*, *Liatris squarrosa*, *Lithospermum* sp., and *Viola pedatifida* among some of the more important forbs that decrease under grazing. Among plants that tend to increase under grazing Poa pratensis, Bouteloua curtipendula, Panicum scribnerianum, Carex pennsylvania, Achillea sp., Aster ericoides, and Solidago rigida are some of the more important.

There are differences among grass species themselves in their response to grazing. Palatability, and other factors cause livestock to select some grasses more readily than others (9, 15, 116).

Branson (15) lists two factors important in survival of grasses. These are the height to which growing points are elevated and the ratio of reproductive to vegetative stems. Panicum virgatum and Elymus canadensis have a high ratio of reproductive to vegetative stems and have a growing point that is thrust above the ground early in the season. As a result, these grasses decrease rapidly under grazing. Andropogon gerardi has a growing point that is thrust above ground later in the season and is more resistant to grazing than Panicum virgatum or Elymus canadensis. The growing point of Andropogon scoparius is also thrust above the ground later in the season, but a very high ratio of fertile to vegetative stems is an important cause of the lack of resistance of this plant to grazing. Boutalous curtipendula has a growing point that remains very near the surface throughout the season, with only a moderately high ratio of fertile to vegetative stems and is thus somewhat resistant to grazing. Poa pratensis has a growing point that remains below the surface throughout the season, has a very low ratio of fertile to vegetative stems, and is thus able to replace the taller grasses under grazing. The flowering stem of Poa pratensis does not elongate until the growing point has entered the reproductive phase, whereas in most of the native grasses such as Panicum virgatum the earliest internodes elongate previous to the development of the reproductive phase. This would explain why many investigators have reported Poa pratensis increasing markedly at the expense of the tall grasses such as Andropogon gerardi, and A. scoparius under both grazing and mowing in the prairie (2, 8, 25, 81, 95, 118, 120).

Forbs behave differently to the various systems of removal of vegetation because of differences in growth characteristics (77). E. C. Conard (25) reported that many important forbs decrease under early cuttings. He obtained reductions in the density of forbs of 19 per cent after six years of early cutting and increases of 49 and 87 per cent under mid-season and late cuttings, respectively.

Initial growth of grassland herbage in the spring is made at the expense of carbohydrates stored in basal organs of the plant the preceeding season (14). Concentration of carbohydrates in both herbage and basal organs is related to rate of herbage growth, and this relationship is maintained throughout the annual cycle of growth. Stored carbohydrates are at their lowest concentration a few weeks after growth starts in the spring and further storage is delayed until most of the annual growth is produced. Not all stored food is used in normal early growth of perennial grasses. However, if this new growth is removed by early clipping or grazing, there results a diminution of reserve food. A second close clipping further depletes the reserves, and continued close clipping throughout the growing season can either seriously injure the plant or cause its eventual death. In this weakened condition the plant is subject to damage from extremes of heat or cold. As a result, other plants such as Poa pratensis, which are better adapted than prairie plants to compete under close clipping, may take over (6, 9, 13, 14, 27, 69, 71). The decrease of many important native forage species under intensive clipping or grazing can be explained on this basis.

Albertson and Weaver (6) observed an increase of 11 per cent in total yield of Andropogon scoparius as a result of the first year of frequent clipping. They concluded that this increase was made at the expense of stored food material in the roots, based on the fact that a second year of this severe clipping reduced yields by 46 per cent compared to the control. Frequent clipping for a third year further reduced yields to 56 per cent of the yield from the second year of frequent clipping.

Weaver and Hougen (118) reported that the total yield of Andropogon scoparius plots clipped six times during the season was 11 per cent greater than the control the first year but only 60 per cent of the control the second year. Under the same clipping treatment, Andropogon gerardi yielded about the same as the control the first year and only about 72 per cent of the control the second year. Mixed stands of these two grasses gave similar results. They concluded that loss of photosynthetic area resulted in decreased yield and vigor and that yield and vigor vary inversely with frequency of clipping. Aldous (7) reported that density of vegetation (mostly Andropogon scoparius and A. gerardi) decreased 60 per cent in three seasons when clipped at 2 week intervals, while clipping at 3 week intervals resulted in only 13 per cent reduction. Similar results have been obtained by other investigators working with other prairie grasses (14, 16, 17, 38, 62, 74, 75, 81, 111, 118).

McCarty and Price (69) reported that plants clipped near the end of the growing season yielded more forage and more carbohydrate reserves than those clipped near the beginning of the growing season. However, Blaisdell and Pechanec (14) found that clippings made later in the growing season resulted in less chance for regrowth and storage. They concluded that mowing is most serious when made after the date when substantial regrowth is impossible, which would be during the active reproductive phase and the forepart of normal carbohydrate storage following seed test.

As a result of a decrease in to growth from frequent removal by mowing or grazing, there is generally a reduction in root growth of the plant (13, 16, 18, 30, 41, 44, 80, 92, 107, 118). Branson (16) reported that frequent clipping had a more pronounced effect on root production than on shoots. This decrease in root production is manifest in both reduced quantity and depth of root penetration. Weaver and Darland (113) reported that with frequent clipping the depth of root penetration decreased from 8 feet to 3 feet for _Andropogon scoparius_, from 15 to 7 for _Andropogon gerardi_, from 18 to 7 for _Panicum virgatum_, and from 12 to almost 0 for _Stipa spartea_. Accompanying this decrease in depth of roots was a decrease in weight of roots per plant from 1.45 grams to 0.02 grams for _Andropogon scorparius_, from 2.27 to 0.37 for _Andropogon gerardi_, from 2.95 to 0.16 for _Panicum virgatum_, and from 0.49 to almost 0 for _Stipa spartea_.

The nutritive value of the forage is also affected by frequency of clipping. Crude protein and mineral content generally increased in plants under early or frequent clipping (7, 10, 25, 55, 76, 95). Aldous (7) reported that plots clipped less frequently gave a greater yield than plots clipped frequently. However, the nutritive value of the more frequently clipped plots was higher. It is generally concluded, however, that the higher nutritive value does not compensate for the decrease in yield and possible injury to the plants caused by frequent clipping (7, 118).

The height at which plants are clipped or grazed is also important. In general, the higher the plant is clipped, the less the plant is injured (7, 16, 18, 44, 47).

Grazing of prairie in Iowa and Wisconsin is considered to be more destructive than mowing (2, 27). Compaction of the soil and the selective and severe grazing of key prairie grasses favor competing bluegrass, redtop, timothy, and other introduced plants (2).

<u>Controlled burning</u>

The burning of grass is a world-wide practice of ancient origin, particularly in humid regions where grass does not cure into palatable winter forage (8, 45). Fire was reportedly used by the Indians of North America to facilitate hunting of bison and elk and to attract other game animals (8). Fires started by lightning and by the Indians were believed to have been the chief factor in perpetuating and extending the vast expanse of prairie in and adjacent to forest climax regions (70, 97, p. 383).

The effects of fire on vegetation, soil, and alteration if microclimate is a highly controversial subject. Although investigators agree that native grasslands have been and are subject to frequent and sometimes extensive burning, the interpretation of fire as a tool for range and pasture improvement has fluctuated greatly (31, 36, 45, 46, 54, 65, 66, 68, 97).

Stoddart and Smith (97, p. 383) have stated that,

> Though fire is harmful in some degree to all vegetation, the severe effect it has upon trees does not occur in herbaceous plants, for in these the perennial parts are not above the ground. Fire may be a terribly destructive force in forest and in certain brush and grass ranges, but there is much evidence that controlled burning may be beneficial to rangeland.

Graber (43) as early as 1926 concluded that the burning of pasture in early spring is not a common practice in some localities, but is quite generally recognized as being beneficial. Generally, it is regarded as having a stimulating effect on early spring growth of perennial pasture grasses. Aldous (8) reported that burning at least every other year is desirable, if not essential on Kansas bluestem pastures. Curtiss and Partch (27) reported burning to be essential in the re-establishment of native prairie on abandoned farmland in southern Wisconsin. In a paper on the use of fire in game management, H. L. Stoddard (96) stated that fire could be an important tool if correctly and scientifically applied, but damaging if wrongly applied.

Many investigators have reported very detrimental effects both on soil and vegetation as a result of burning (36, 40, 54). Hopkins *et al.* (54) stated that the detrimental effects of burning either accidentally or otherwise could be overemphasized. Burning has often been justified on the basis of some more specific uses such as removal of excess organic material, removal of harmful insects and snakes, increasing nutritive value of grasses, obtaining more even use on a given range, seed bed preparation, fire protection, and silvicultural purposes (2, 46, 65, 66, 68, 89).

Burning of litter on the surface of the soil returns nitrogen to the atmosphere and destroys some organic matter (36, 40, 45, 105). However, Wahlenberg et al. (105) concluded that this destruction of organic matter and escape of nitrogen is not a serious loss since on lands protected from fire, nitrogen also returns to the atmosphere by slow volatilization in the process of weathering and decay. Fire merely speeds up the reaction. Fowells and Stephenson (40) reported that although fire may destroy the top organic and humifying material, the immediate effects of a fire are generally favorable. They found that burning speeded up nitrification, and this higher rate of nitrification was maintained throughout the 12 weeks of their study. It was also noted that, although nitrogen may be lost, ash becomes an immediately available source of nutrients. However, they concluded that repeated burning would result in a condition of insufficient organic matter in the soil for humification. Thus, natural processes occurring in soils would become inoperative and result in impoverished soils and reduced growth through lack of nutrients, reduced moisture-holding capacity, and generally unfavorable conditions. Elwell et al. (36) reported similar results and also stated that, following burning, immediately available nutrients may be lost by leaching or erosion.

Greene (45) found a slight increase of organic matter in the top six inches of soil after burning. He accounted for this on the basis of the greatly increased top and root growth of grasses and legumes as a result of burning. Burning is said to be beneficial when it removes thick accumulations of organic debris with such high carbon:nitrogen ratios that growth has stagnated (29, p. 221). In the ordinary decomposition of litter, fungi predominate in the upper layer and give off acids which may inhibit the growth of nitrate-forming bacteria. Because of the increased availability of calcium, phosphorus, and potassium with burning, the pH of a slightly acid soil is raised to near the neutral point, which is more favorable to nitrifying organisms. Thus, at least temporarily, improved conditions for plant growth may result (29, p. 221, 40, 104). Other investigators have reported increased counts of soil bacteria on burned areas compared to unburned areas (45, 92, 105, 106). Wahlenberg *et al.* (105) for instance found soil bacterial counts to be highest in burned and grazed areas and to decrease in order through burned and ungrazed areas, unburned and grazed areas to unburned and ungrazed areas. They concluded, however, that the increased soil temperature on the burned areas was partly responsible for the increase in bacterial counts.

The increase in soil temperature was found to be due chiefly to the removal of the insulating effect of the mulch, composed of litter and duff and to the darker exposed soil surface which absorbed more solar radiation. Some investigators have reported that in addition to the lower temperature under a mulch there is also less temperature fluctuation (20, 35, 42). Steiger (94) measured soil temperature at depths of 1, 3, and 6 inches on burned, mowed, and protected areas and found the temperature to be highest for all depths on the burned area and lowest for all depths on the protected area. There is also a close relationship between rising soil temperature and increasing growth rate from the time growth begins until about the end of April (20, 58, 119).

One of the most important effects of the removal of mulch is the alteration of water relations. A mulch will intercept a considerable amount of precipitation and return it to the atmosphere by evaporation (21). The extent of this interception will depend on the type of mulch covering the surface, and the amount and intensity of the precipitation (21, 33, 83, 121). Percentage interception is greater for low intensity showers than for high intensity ones. A mulch also tends to increase snow accumulation and snow melting time (35, 93). The rate of infiltration and percolation is also greatly influenced by the presence of mulch. A mulch will generally increase the rate of infiltration of moisture into the soil (32, 33, 34, 35, 45, 53, 94, 99, 101, 119). Duley (32) applied excess moisture for five hours to a soil with and without a mulch. He reported the intake of water into the soil with a mulch covering to be constant at 1.2 inches per hour. The rate of intake on an area not covered by mulch dropped after 30 minutes and became constant at 0.25 inches per hour. He concluded that wetness did not reduce rate of intake, but the immediate surface conditions did. Also, more precipitation in several small rains will get into the subsoil because the surface soil will be more moist and will not absorb as much moisture (33, 85). Following a rain, if the soil is protected by a mulch covering, the rate of drying of the surface soil is reduced and the period of adjustment downward is prolonged. If another rain should come in a few days while the soil is still moist, the rain will be more effective since less of it would go to wetting the dry surface soil (83). In general, better conditions for water storage result under a mulch compared to an area without a mulch covering (20, 42, 52, 78, 83).

The presence of a mulch also greatly reduces loss of soil moisture from the surface soil by evaporation (12, 34, 42, 53, 66, 83, 88, 94, 101, 121). Russel (83) reported that a mulch of 1.5 inches reduced evaporation 91 per cent. He thought that about 36 per cent was probably due to shade and 55 per cent due to reduced temperature. He also concluded that a light mulch of one-half inch was as effective in this respect as a heavier mulch.

Another important consideration of mulches is that of erosion control. Besides reducing wind and water erosion (33, 34, 35, 42, 83, 101, 119), it also reduces erosion due to raindrop impact by breaking the force of the impact, promoting aggregation, and preventing compaction (12, 33, 73, 97).

The alteration of temperature and soil moisture due to the removal of mulch by burning are of paramount importance in understanding subsequent effects on the vegetation. Another important factor to consider is the time of burning (2, 43). Aikman (2) has recommended that the soil should be frozen and the vegetation sufficiently dry to insure the removal of litter and duff as well as the standing dry vegetation. Burning, however, should not be done early enough to expose the bare soil to severe winter weather or to lose the beneficial effect of the litter and duff in trapping snow and the consequent improved conditions for retention of moisture for too long a period. For these reasons, fall burning is not recommended. However, if burning is done too late in the spring, there is danger of injury to crowns, rhizomes, and shallow roots of the plants (2, 43). If an area is burned too late in the spring the increased soil temperature would enhance the growth of some plants and, if a late freeze were to occur, these early growing plants could be severely damaged (96). In burning studies conducted on bluestem pasture in Kansas, Aldous (8) found greatest reduction in yields on plots burned late in the fall and least reduction in yield on plots burned in late spring. Elwell _et al._ (36) obtained similar results.

Many investigators have noted an earlier start of growth in the spring on burned areas compared to unburned areas (2, 22, 43, 51, 58, 119). Clarke *et al.* (22) found a close relationship between rising soil temperature and increasing rate of growth from initiation of growth until the end of May when soil moisture rather than temperature became a limiting factor. Hensel (51) reported similar findings but further noted that as the growing season advanced the unburned area tended to "catch up". According to Weaver and Rowland (119) the general effect of an excessive mulch is to cause the soil to warm up more slowly in the spring. As a result of the slower start by plants under a mulch covering, the earlier and smaller species are greatly handicapped and tend to disappear.

On an ecotone between prairie and forest in Wisconsin, Curtis and Partch (27) observed that *Poa pratensis* and *Poa compressa* were almost in complete control and many prairie species could not compete successfully. After six years of spring burning the bluegrasses were reduced to one-fifth their original cover and as a result the native prairie species were able to increase. Other investigators have also reported injury to *Poa pratensis* from spring burning (8, 43, 51, 81). Robocker and Miller (81) reported *Elymus canadensis* to be similarly injured by the early spring burning. They attributed this injury to the fact that cool season grasses started growth very early and suffered damage because of high temperatures of the fire, whereas the warm season grasses, still in dormancy suffered little or no damage.

In addition to an earlier initiation of growth on burned areas, compared to protected areas, Aikman (2) reported an increase in flowering and fruiting of plants on the burned area as well as an increase in height of flowering stems. Similar findings have been reported by Curtis and Partch (28), Burton (19), and Dix and Butler (31).

In studies on seed yield of certain grasses, Burton (19), found fertilizer application increased seed yield. He reported that moderate applications of nitrogen had an advantageous effect, but when phosphorus and potassium were added no additional increases in seed yield were obtained. When it was pointed out to him by W. O. Shepherd that native grasses which rarely flower flowered profusely after burning, this additional treatment was applied. He found a large increase in number of seeds per acre from burning alone. When nitrogen was applied after burning he obtained an even larger increase in seed production.

On planted stands of <u>Andropogon gerardi</u>, Curtis and Partch (28) found that the grass grew vigorously, but did not flower. However, when parts of the area were burned they flowered profusely. They hypothesized that this effect could be due to the direct heat of the fire on buds of the crown, removal of accumulated litter or liberation of mineral fertilizers. To test these hypotheses they carried on additional experiments and found, as did Hopkins (52), that removal of litter increased the basal area of plants and number of flowers per stem. They concluded that the most important factor in suppression of flowering was the covering of the crowns by litter because removal of the litter either by fire or raking off increased flowering six-fold and seed-stalk height 60 per cent. The addition of the ash was responsible for only a very small further increase. The direct heat of the fire had no effect. Dix and Butler (31) also noted an increase in flowering of some prairie species, but reported that this may not be true for all species. They further noted no difference in flowering on burned and unburned areas at the end of the second growing season. Besides the increase of flowering stems, they observed a decrease in basal area of some species as <u>Andropogon scoparius</u>. Evans and Grover (37) stated that under controlled conditions, grass stems which produce reproductive parts, produce fewer leaves than those plants that remain vegetative. Thus, the stimulation to flower produced by burning or mulch removal will necessarily reduce the number of leaves and show a decrease in cover.

EXPERIMENTAL

Materials and Methods

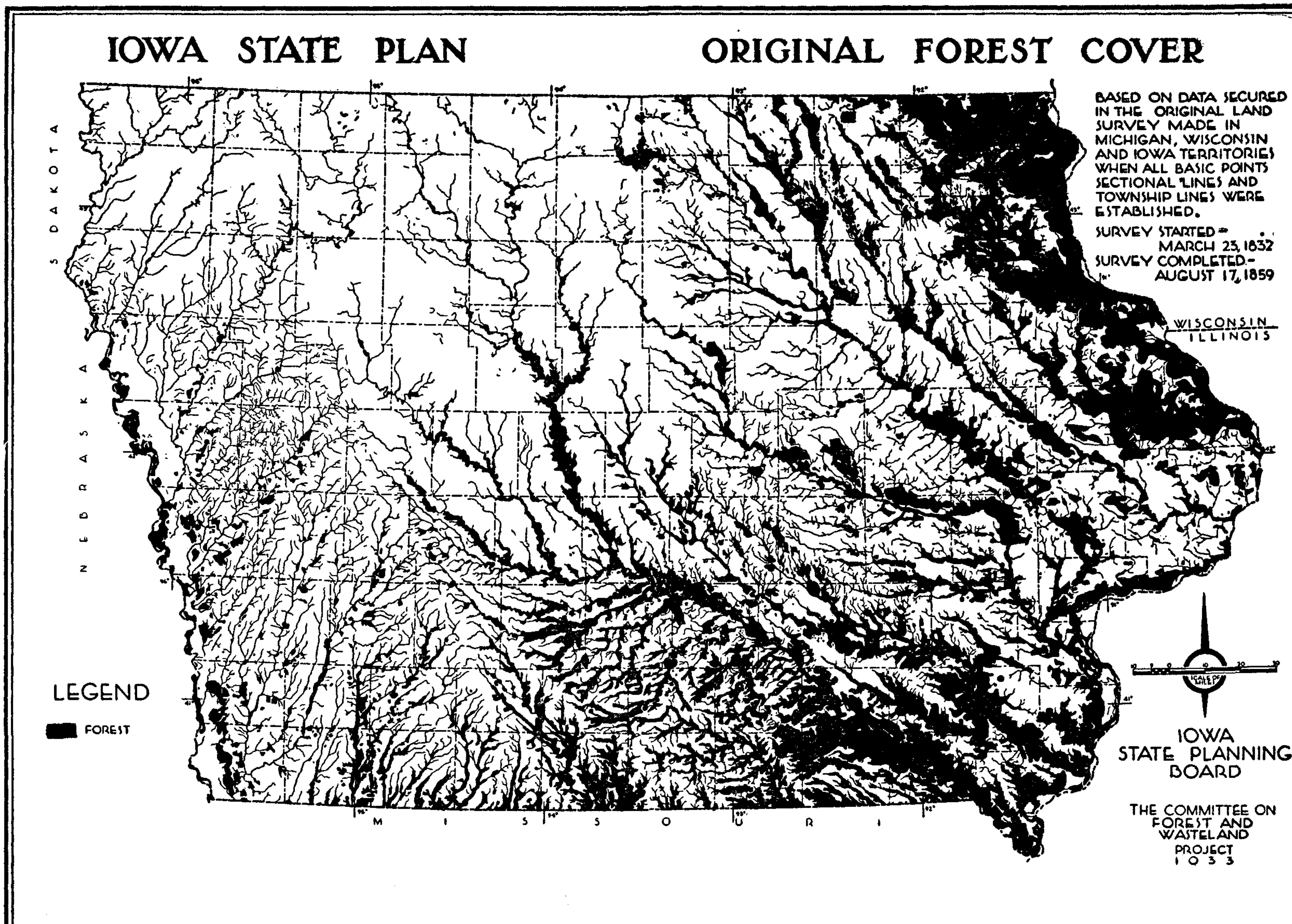
Experimental area

This study was conducted on that portion of the Hayden prairie (160 acres) located in the northeast quarter of section 33, Chester Township in the northeastern part of Howard County (Figure 1). Howard County is located in northeastern Iowa, in the third tier of counties west of the Mississippi River. On the north, it borders the state of Minnesota.

The Hayden prairie was acquired by the Iowa State Conservation Commission in 1945. Prior to this date, the tract was in the ownership of one family for 78 years. During that time it was cut for hay and occasionally pastured.

The gently rolling Hayden prairie is in the Iowa drift soil parent material area, and in the plastic till variant of the Carrington type of the Carrington-Clyde soil association area. The soils are Carrington silt loam, plastic till phase, Floyd silt loam, and Clyde silt loam (48, 79). A ridge of high ground extending northwest from the southeast corner of the area divides the drainage, two-thirds to the northeast and one-third to the southwest. This upland, with its long slopes, occupies about 60 per cent of the area and is covered by the plastic till phase of the Carrington silt

Figure 1. Map of the state of Iowa, showing the extent of the original native prairie and forest cover. The location of the Hayden prairie is indicated by ■ .


IOWA STATE PLAN
ORIGINAL FOREST COVER
BASED ON DATA SECURED IN THE ORIGINAL LAND SURVEY MADE IN MICHIGAN, WISCONSIN AND IOWA TERRITORIES WHEN ALL BASIC POINTS SECTIONAL LINES AND TOWNSHIP LINES WERE ESTABLISHED.
SURVEY STARTED - MARCH 23, 1832
SURVEY COMPLETED - AUGUST 17, 1859
S DAKOTA
NEBRASKA
MINNESOTA
WISCONSIN
ILLINOIS
MISSOURI
LEGEND
FOREST
IOWA
STATE PLANNING
BOARD
THE COMMITTEE ON
FOREST AND
WASTELAND
PROJECT
1933

loam. The Clyde silt loam occupies about 15 per cent of the area along the natural drainages. The Floyd silt loam occupies a narrow strip a few rods in width between the Clyde and Carrington and covers about 25 per cent of the area.

The Hayden prairie is located within, but at the extreme edge of the prairie association in northeastern Iowa (87, 101). The prairie under study is within Thornthwaite's (98) climatic province which is described as subhumid microthermal with adequate moisture at all seasons. It lies within the northeastern border of the prairie soils group (57, 67, 74). According to Transeau's map of precipitation-evaporation ratios, based on 1887-8 precipitation and evaporation data, the Hayden prairie would lie between 0.80 and 1.00 with a value of approximately 0.95 (100).

This investigation was concerned primarily with the upland portion (60 per cent) of the tract, the soils of which are classified as Carrington silt loam, plastic phase. The bordering intermediate areas of Floyd silt loam (25 per cent) and the Clyde silt loam areas of the two drainages (15 per cent) were studied for the purpose of comparing the vegetation as to composition and structure with that of the upland area.

The vegetation on the Floyd silt loam and of the Clyde silt loam was classified as lowland prairie. The five dominants of this lowland prairie were, in order, from wet, poorly aerated sites of Clyde soil to relatively drier lowland sites of the Floyd soil, _Spartina pectinata_, _Panicum virgatum_, _Elymus canadensis_, _Sorghastrum nutans_, and _Andropogon gerardi_.

The two chief dominants on the Clyde silt loam in the two drainages were _Spartina pectinata_ and _Panicum virgatum_. The three other lowland dominants were sparsely interspersed in the better drained situations. Associated with the two dominants were species of large, wet land forbs: _Cicuta maculata_, _Lobelia spicata_, _Helianthus grosseserratus_, _Liatris pycnostachya_, and _Cacalia tuberosa_. The chief dominant of the lowland prairie on the Floyd silt loam bordering the drainages was _Andropogon gerardi_ which constituted one-half or more of the grass cover. _Panicum virgatum_, _Sorghastrum nutans_, _Elymus canadensis_, and _Muhlenbergia racemosa_ made up most of the remaining grass cover. The first and last named of these four grasses formed occasional patches of a few to several square feet in area. The forb population was composed of a diversity of upland and lowland prairie species adapted to conditions of this intermediate area.

The Hayden upland prairie, developed under the mesic conditions of the prairie peninsula border in northeastern Iowa, is a very luxuriant upland prairie community (Figure 2). The dominant and chief sub-dominant component species of this community are ranked in order of the frequence x abundance index in Table 1. These values were obtained from a vegatative

Figure 2. General aspect of upland prairie.

Upper: Early estival aspect showing conspicuous forbs in flower distributed among the grasses.

Lower: Late estival aspect showing forbs when not in flower and the obvious dominance of the many grasses.

Table 1. The most important grasses and forbs in the Hayden prairie in order of frequence x abundance index (on weight of vegetation basis)[a]

Scientific name	Common name	Frequence	Frequence x abundance
Sporobolus heterolepis Gray.	prairie dropseed	82	22.7
Andropogon scoparius Michx.	little bluestem	88	15.7
Andropogon gerardi Vitman	big bluestem	94	15.7
Panicum virgatum L.	switch grass	76	6.9
Poa pratensis L. and *P. compressa* L.	Kentucky bluegrass and Canada bluegrass	66	5.8
Sorghastrum nutans (L.) Nash.	Indian grass	62	5.8
Stipa spartea Trin.	porcupine grass	44	2.4
Muhlenbergia racemosa (Michx.) BSP.	muhley grass	20	1.9
Phleum pratense L.	timothy	82	1.9
Koeleria cristata (L.) Pers.	Junegrass	48	1.8
Amorpha canescens Pursh.	leadplant	44	1.3
Heliopsis helianthoides var. *scabra* (Dunal) Fern.	false sunflower	14	1.3
Aster azureus Lindl.	aster	62	1.2
Baptisia leucophaea Nutt. and *B. leucantha* T. & G.	baptisia and white baptisia	16	1.1
Aster ericoides L.	aster	42	0.9
Achillea lanulosa Nutt.	yarrow	70	0.8
Coreopsis palmata Nutt.	tickseed	24	0.7
Agrostis alba L.	redtop	26	0.7
Panicum oliganthes var. *scribnerianum* (Nash.) Fern.	panicum	26	0.6

[a]Nomenclature follows Fernald (39).
The frequence x abundance index numbers are from Moyer (72).

Table 1, continued

Scientific name	Common name	Frequence	Frequence x abundance
Zizia aurea (L.) W.D.J. Koch and *Z. aptera* (Gray) Fern.	golden alexanders and zizia	42	0.6
Petalostemum purpureum (Vent.) Rydb. and *P. candidum* (Willd.) Michx.	purple prairie clover and white prairie clover	44	0.6
Helianthus grosseserratus Martens and *H. laetiflorus* var. *rigidus* (Cass.) Fern.	sunflower and sunflower	10	0.5
Eryngium yuccifolium Michx.	rattlesnake master	12	0.4
Liatris pycnostachya Michx.	blazing star	16	0.4
Cacalia tuberosa Nutt.	plantain	6	0.4
Aster laevis L.	aster	12	0.3
Solidago gigantea var. *leiophylla* Fern.	goldenrod	10	0.3
Solidago altissima L.	golden rod	18	0.3
Cicuta maculata L.	water hemlock	10	0.3
Lespedeza capitata Michx.	bush clover	14	0.2
Liatris scariosa (L.) Willd.	blazing star	6	0.2
Cirsium discolor (Muhl.) Spreng. and *C. hallii* (Canby) Fern.	thistle and thistle	8	0.2
Echinacea pallida Nutt.	coneflower	18	0.2
Silphium laciniatum L.	compass-plant	6	0.2
Spartina pectinata Link.	slough grass	4	0.1
Antennaria neglecta Greene	pussytoes	34	0.1
Senecio integerrimus Nutt.	groundsel	6	0.1
Vicia americana Muhl.	vetch	24	0.1

analysis of an area which included approximately one-third of the bordering intermediate Floyd silt loam area with the upland prairie and as a result, the frequence x abundance values of some of the lowland prairie plants are too high.

The three chief dominants of this community are *Sporobolus heterolepis*, prairie dropseed; *Andropogon scaparius*, little bluestem, and *Andropogon gerardi*, big bluestem. The yield of these three plants equaled the total yield of all other plant species making up the vegetation of the upland prairie (Table 1). Prairie dropseed and little bluestem are bunch grass dominants of the upland prairie which form crowns of about one inch to a foot or more in diameter. Big bluestem, a lowland prairie sod-former dominates the area between the bunches. *Stipa spartea*, porcupine grass, forms numerous smaller bunches among the bunches of dropseed and little bluestem as does *Koeleria cristata* to a lesser degree. These two species and *Boutelana curtipendula* are confined to the drier, better drained parts of the upland prairie area. *Sorghastrum nutans*, Indian grass, is associated with big bluestem in occupying the inter-bunch grass space in the ratio of about 1:3. The lowland prairie grasses over-top the upland grasses to the extent that degree of occupancy of the area appears to be greater than it is. On the basis of percentage of basal area at ground level, the upland prairie dominants, because of the formation of crowns, have a ratio to the lowland prairie dominants of 8:2.

The combined frequence x abundance in the prairie of Poa pratensis, Kentucky bluegrass; P. compressa, Canada bluegrass; Phleum pratense, timothy, and Agrostis alba, redtop is 8.4 per cent. Bluegrass was found in 66 per cent of the quadrats, timothy in 82 per cent, and redtop in 26 per cent (Table1). These relatively high frequence values seem to verify the report that cattle on hay feed had previously grazed the tract. At present the bluegrass, timothy, and redtop plants lack size and vigor but their presence throughout the tract constitute a threat of permanent invasion if grazing or excessive mowing reduces the vigor of the prairie vegetation.

Many species of forbs are components of this upland prairie community. Those of greatest frequence x abundance are listed in Table 1. The number of species is in excess of 100. Despite this fact, they constitute a smaller proportion of the dry matter yield of vegetation than is generally assumed on the basis of their showy appearance during flowering. Many subdominant grasses and sedges, including bluegrass, timothy, and redtop, contribute materially to the 50 per cent yield of plants other than that of the three chief dominants.

Treatment applications on the experimental area

Since its purchase in 1945, the Hayden prairie was under complete protection until 1954 (48). As a result of quantitative studies of vegetation, litter and duff, it was determined that accumulated organic material was interfering with normal growth, and the recommendation was made to conduct a burning experiment. Eight pairs of blocks, each 440 by 440 feet were selected in upland prairie. The one of each pair to be burned was determined by chance (2, 59). These eight plots were burned by personnel of the Conservation Commission on February 19, 1954. The decision was made in the fall of 1954 to burn the northern two-thirds of the Hayden prairie during the winter. Because of the late melting of snow, the burning, which was done by personnel of the Conservation Commission, was not carried out until March 15, 1955. On the west side of the prairie the fire jumped the backfire strip and burned a strip about 220 feet wide on the west side of the southern one-third that was originally intended to be left unburned. As a result of the 1955 burning, there was a pattern of areas burned in 1954 only, areas burned in 1955 only, areas burned in both 1954 and 1955, and unburned areas. In two separate locations in the upland prairie, blocks of the four burning combinations formed a square so that all treatments could be compared within a very short distance of each other. The southern-most location is hereafter referred to as location 1 and the northern-most location as location 2. In order to have an additional location for comparison, it was necessary to have the areas of two of the four burning combinations somewhat separated from the other two. Although it is recognized that having two of the treatments separated from the other two is not good experimental procedure, the great similarity of physiognomy, floristics, and habitat of this upland prairie would justify the use of data from these separated treatments for comparison with data obtained from the treatments of location 1 and 2 (2, 72). During the first week in April, 1955 a one-tenth acre station was laid out in each treatment in each of the three locations.

In the fall of 1955 plans were made to burn additional areas the following winter. Because of weather conditions the burning was not carried out until April 13, 1956. A strip approximately 120 feet wide, extending along the eastern side of the tract from the southeast corner for one-quarter mile was burned. An area 140 feet by 125 feet on the west side of the tract near the southwest corner was also burned. As a result of the 1956 burning, the following treatment combinations were available for study: areas burned in 1954 only, in 1955 only, in 1956 only, in 1954 and 1955, in 1954 and 1956, in 1954, 1955, and 1956, in 1955 and 1956, and unburned areas. Since the area burned all three years was located between, and in close proximity to both location 1 and location 2, the southern half was considered to belong to location 1 and the northern half to location 2. Near the end of the 1955 growing season, when most of the grasses had already set seed, part of the northern two-thirds of the prairie was mowed and baled by commercial equipment. This allowed observations to be made on an additional management practice. In 1956, after most of the grasses were mature, a large part of the prairie was again mowed with new, heavy equipment and observations made to compare the effectiveness of mowing with other methods of management in keeping with the objectives of maintaining a prairie reserve.

Climatological factors

Soil temperature. Soil temperature measurements were taken on burned and unburned areas at various dates throughout the 1955 and 1956 growing season at depths of one-half, two, and five inches. Measurements were usually made between 1:00 and 2:00 P.M. The thermometers were placed in the soil and covered with light-colored wooden tubes.

Air temperature. Maximum and minimum air temperature data were taken on burned and unburned areas at various dates throughout the 1955 and 1956 growing seasons. The thermometers were situated about one inch above the soil surface.

Weather Bureau data. Temperature and precipitation data were obtained from records of the Cresco weather station located about four miles south and 12 miles east of the Hayden prairie and the Saratoga weather station located about four miles south of the prairie. Precipitation-evaporation ratios of the long time average and for the 1954, 1955, and 1956 growing seasons were calculated from data of the Cresco weather station.

Soil factors

Soil moisture determinations. Soil moisture determinations were obtained at various dates during both the 1955 and 1956 growing seasons. Soil samples were weighed in the moist field condition in the laboratory, dried to constant weight in an oven at 105°C., and reweighed. The moisture determinations were calculated on the basis of the oven-dry weight. From volume weight determinations taken at the same depth as the soil moisture measurements (72), these data were recalculated to express the moisture both in per cent water on a volume basis and actual inches of water in the profile. In 1955 measurements were taken in each treatment, in each of three locations and in 1956 the measurements were taken in all treatments of locations 1 and 2 only.

Wilting percentage determinations were made on the upland prairie soil obtained from each depth at which soil moisture content was measured. After permanent wilting, an approximate 100 gram soil sample was taken from the soil-root mass and the percentage moisture determined on the basis of oven-dry weight (3). Wilting percentage determinations were also made for all depths by the soil physics personnel in the Department of Agronomy, Iowa State College, using the pressure membrane apparatus with 15 atmospheres tension (11, p. 283).

Field moisture percentage determinations were also made

(56, 61, p. 37, 103). Soil cores of 58 cubic centimeters were taken with a Coile sampler (24) at various depths in the field. These were brought into the laboratory, carefully saturated with water, placed in a large beaker, and completely surrounded by air-dry soil taken from the same depth. After three days the soil core was removed and from the center part of the core the percentage of moisture determined on the basis of oven-dry weight. These results were checked by bringing sod (with the vegetation clipped at ground level) from the field into the laboratory, saturating the soil, and after three days, taking a soil sample from the center of the sod. The percentage moisture was then determined on the basis of oven-dry weight.

Structural characteristics. Porosity and volume weight measurements were obtained in 1955 by use of the Coile sampler (24). Soil cores were taken in all treatments in each of three locations at two depths, 0-1.5 inches and 3-4.5 inches. These were run according to the procedure described by Lesmer and Shaw (64). Total volumes of air and soil were calculated using 2.65 as the specific gravity of dry mineral soil. The difference in volume as measured by the displaced capillary water upon the oven drying, and the calculated total pore space constituted the aeration porosity.

After completing the porosity determinations of the Coile samples, the ratio of oven-dry weight of soil to its volume was calculated. This value is an expression of the volume weight of the soil.

Nutrient determinations. Organic matter determinations were made using both the Schollenberger method and the ignition method. In 1955, 24 soil samples were taken at two depths, 0-3 inches and 3-6 inches in each treatment at each of three locations. The 24 samples for each treatment in these locations were composited and thoroughly mixed. A sample of soil (0.5 g) was withdrawn from each composited sample and determinations made according to the procedure described by Schollenberger (84). A sample of soil (5 g) was then withdrawn from the composited sample and ignited in a muffle furnace at 600°C. for four hours. The loss of weight was taken as the amount of organic matter in the sample. The loss of weight for a sample of parent material was subtracted from each determination as a correction factor to account for inorganic carbon. In 1956, similar determinations were made with the ignition method from locations 1 and 2.

In 1956, pH, nitrate nitrogen production, available phosphorus, and exchangeable potassium determinations were run on the top 0.75 inches of soil from the various treatments. These same determinations were made on the triple burn and unburned areas at the following depths: 0-0.75 inches, 3-4 inches, 6-7 inches, 12-13 inches, and 18-19 inches. The analyses were made by the Soil Testing Laboratory of Iowa State College according to their standard procedures. Determinations were made from a composited sample of 24 subsamples from each treatment measured.

Vegetation measurements

Measurements on the rate of growth of plants and of seedstalk production were made on the dominant and principal subdominant grasses and forbs. Clipping studies included all herbaceous vegetation.

Plant growth. The average height and stage of development as well as the average number of flowering stems of important grasses and forbs were recorded on each treatment in each location throughout the 1955 and 1956 growing seasons. In 1955, these measurements were taken within each tenth-acre station, and only general observations were made on the remainder of the area in each treatment for each location. During the 1956 growing season these measurements were taken on the entire area of each treatment in each location. In addition, plant collections were made on all treatments at various dates throughout both the 1955 and 1956 growing seasons.

Seedstalk production. During the 1956 growing season, measurements were taken on the number of seedstalks of the dominant and principal subdominant grasses per 1/4000th acre quadrat. These measurements were taken on the various treatments during the latter part of August when most grasses had reached maturity. A sample of 20 quadrats was taken in each treatment and frequency percentage, seedstalk abundance percentage, and the frequence x abundance index calculated for each species. The percentage frequence is the percentage of the number of quadrats that contained at least one seedstalk of the particular species concerned. The percentage abundance is the number of seedstalks of a particular species in all 20 quadrats divided by the total number of seedstalks of all species in all 20 quadrats times 100.

On the 1956 burned area and the adjacent unburned area, individual plants of certain dominant grasses were clipped at the ground level. This was done in late August, when most grasses had reached maturity. Enough plants were clipped so that, where possible, three bundles (5 square inches each) of each species were obtained. These were brought into the laboratory and the number, average height, and weight of seedstalks were determined for one bundle of each species from each treatment. In addition, the average length, total weight and total area of leaves, average length and total weight of sheaths, and the total number and weight of seeds were also determined. The percentage purity and percentage germination of these samples were determined by the Iowa State College Seed Laboratory.

Clipping studies. During the 1955 growing season, clipping studies were conducted using replicated 1/4000th acre quadrats within the tenth-acre station in each treatment at each of the three locations. Five randomly located 1/4000th acre quadrats in each station were clipped on four successive dates, at intervals of approximately 30 days, during the growing season. For comparison, another set of five randomly located quadrats in each station were clipped during the first week of September, at which date most prairie plants had reached maturity. The vegetation was clipped at a height of about one inch above the ground, placed in a paper sack, and brought into the laboratory for drying. The vegetation was weighed air-dry and a sufficient sample oven-dried for correction to a dry weight basis. In locations 1 and 2 in 1956, the same clipping treatments were applied to plots clipped the previous year and to similar sets of randomly located quadrats clipped only in 1956. The same harvesting and weighing procedures were followed except that in addition the grasses and forbs were also separated and weighed.

Additional clipping information was obtained from 1/4000th acre quadrats in the 1956 burned and in an adjacent unburned area and on mowed and unmowed areas.

<u>Litter and duff measurements</u>

The accumulated organic material on various treatments was determined from replicated, randomly located 1/4000th acre quadrats shortly after burning in both 1955 and 1956. These measurements were also made on various treatments at the end of the 1956 growing season. The litter and duff samples were placed in paper sacks, brought into the laboratory, and oven-dried for weighing.

Results

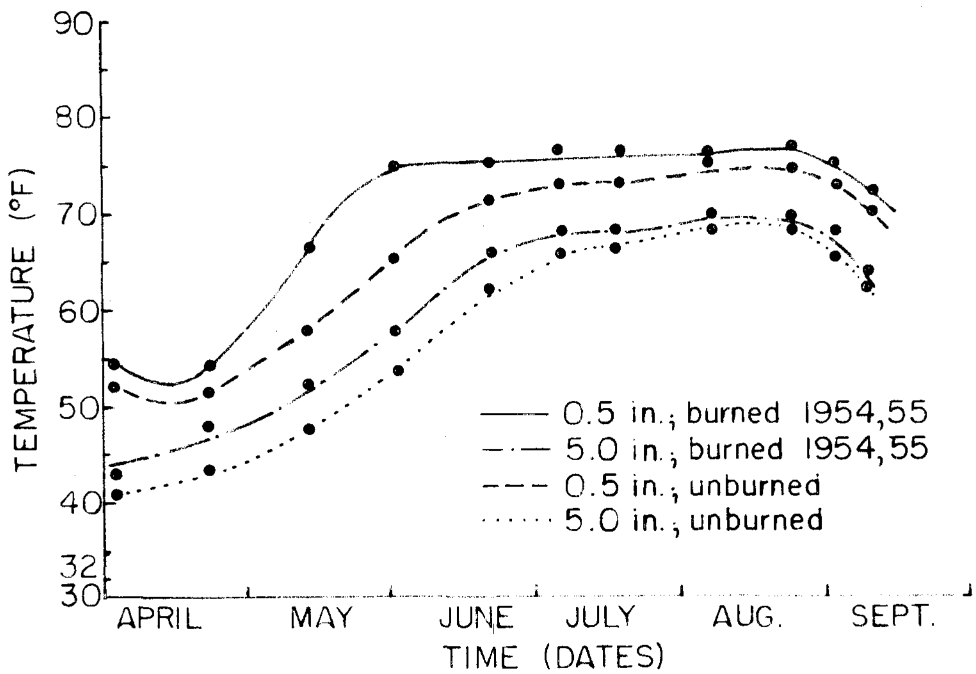
Climatological data

Soil temperature. During the 1955 and 1956 growing seasons, the soil temperature was considerably higher at all depths in the burned than in the unburned areas until July or August after which there was essentially no difference (Figures 3 and 4; Tables 25 and 26). During May and the early part of June the soil temperature at the one-half inch depth was as much as 10^{o}F higher in the burned areas. The difference in soil temperature between the two groups of areas was greater at the one-half inch depth than at the five inch depth. By July, the vegetation had developed to the point where it was almost as effective as the mulch in reducing soil temperature, and the differences in temperature at the various depths in the burned and unburned areas were negligible.

Air temperature. The maximum air temperature one inch above the ground during the 1955 and 1956 growing seasons was about 10^{o}F higher in the burned as compared to the unburned areas until June or July (Figures 5 and 6; Tables 27 and 28). After July the difference was very slight. The minimum air temperature one inch above the ground was higher in the unburned than in the burned areas until the first part of June during both the 1955 and 1956 growing seasons. After June the minimum air temperature was slightly lower in the unburned areas. The

Figure 3. Midday soil temperatures ($^{\circ}F$) at the 0.5 and 5.0 inch depths for burned and unburned areas during the 1955 growing season.

Figure 4. Midday soil temperatures ($^{\circ}F$) at the 0.5 and 5.0 inch depths for burned and unburned areas during the 1956 growing season.


90
80
70
60
50
40
32
30
TEMPERATURE (°F)
0.5 in.; burned 1954,55
5.0 in.; burned 1954,55
0.5 in.; unburned
5.0 in.; unburned
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
TIME (DATES)

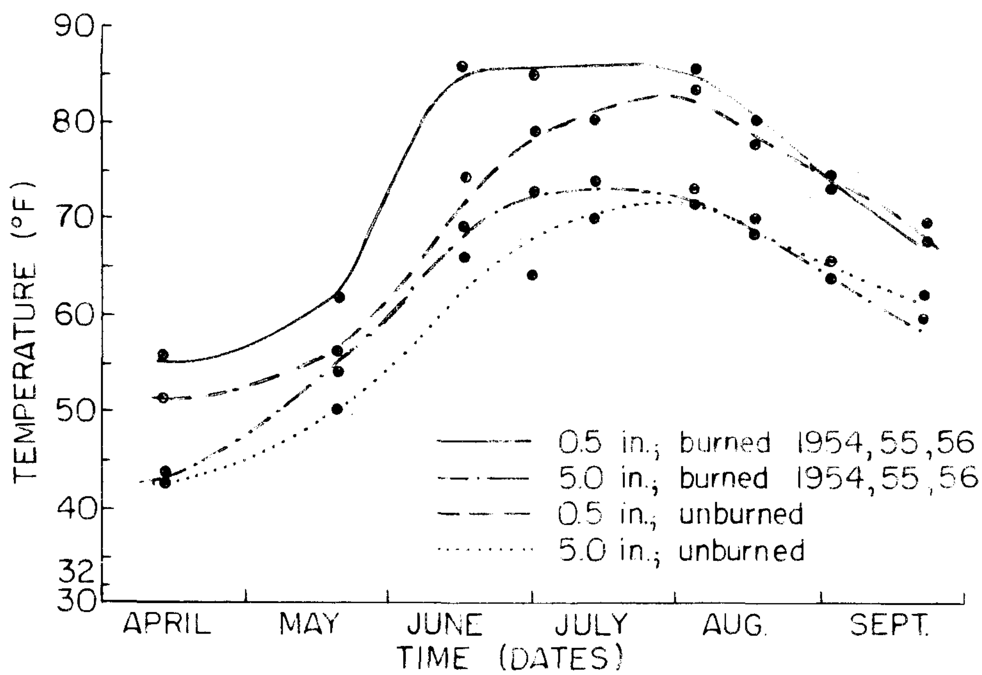
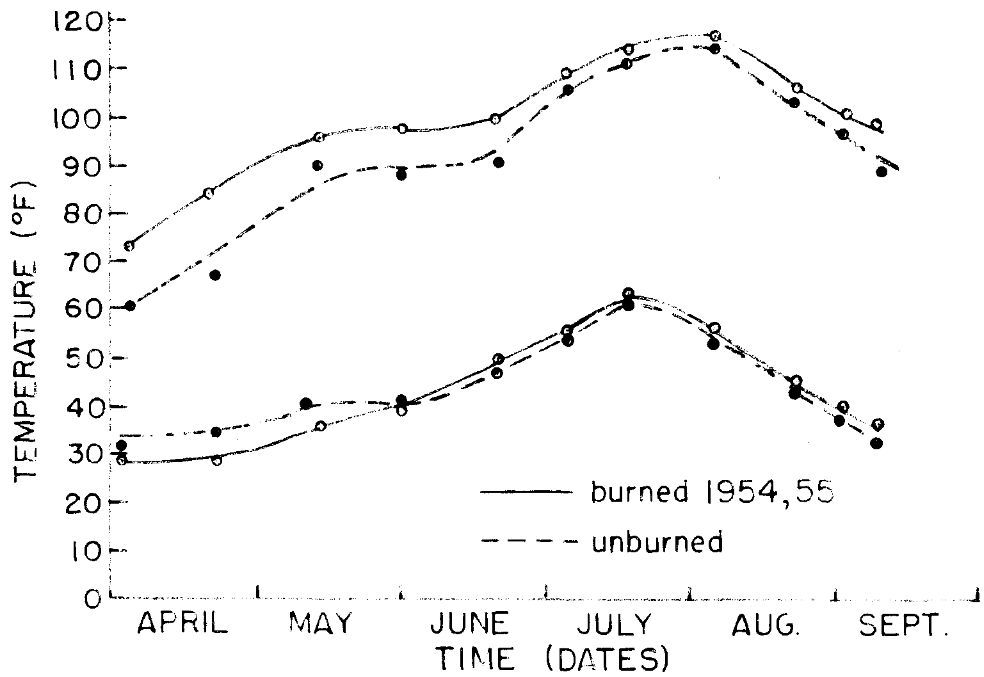
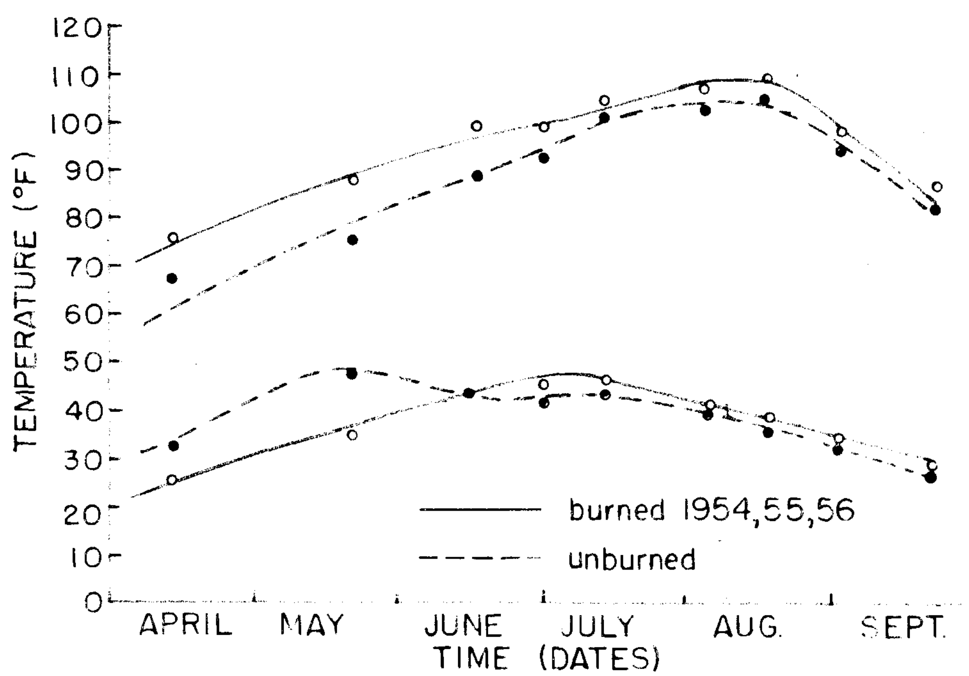

90
80
70
60
50
40
32
30
TEMPERATURE (°F)
0.5 in.; burned 1954,55,56
5.0 in.; burned 1954,55,56
0.5 in.; unburned
5.0 in.; unburned
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
TIME (DATES)

Figure 5. Maximum and minimum air temperatures (^{o}F) on burned and unburned areas taken about one inch above the soil surface during the 1955 growing season.

Figure 6. Maximum and minimum air temperatures (^{o}F) on burned and unburned areas taken about one inch above the soil surface during the 1956 growing season.


120
110
100
90
80
70
60
50
40
30
20
10
0
TEMPERATURE (°F)
burned 1954,55
unburned
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
TIME (DATES)


120
110
100
90
80
70
60
50
40
30
20
10
0
TEMPERATURE (°F)
burned 1954,55,56
unburned
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
TIME (DATES)

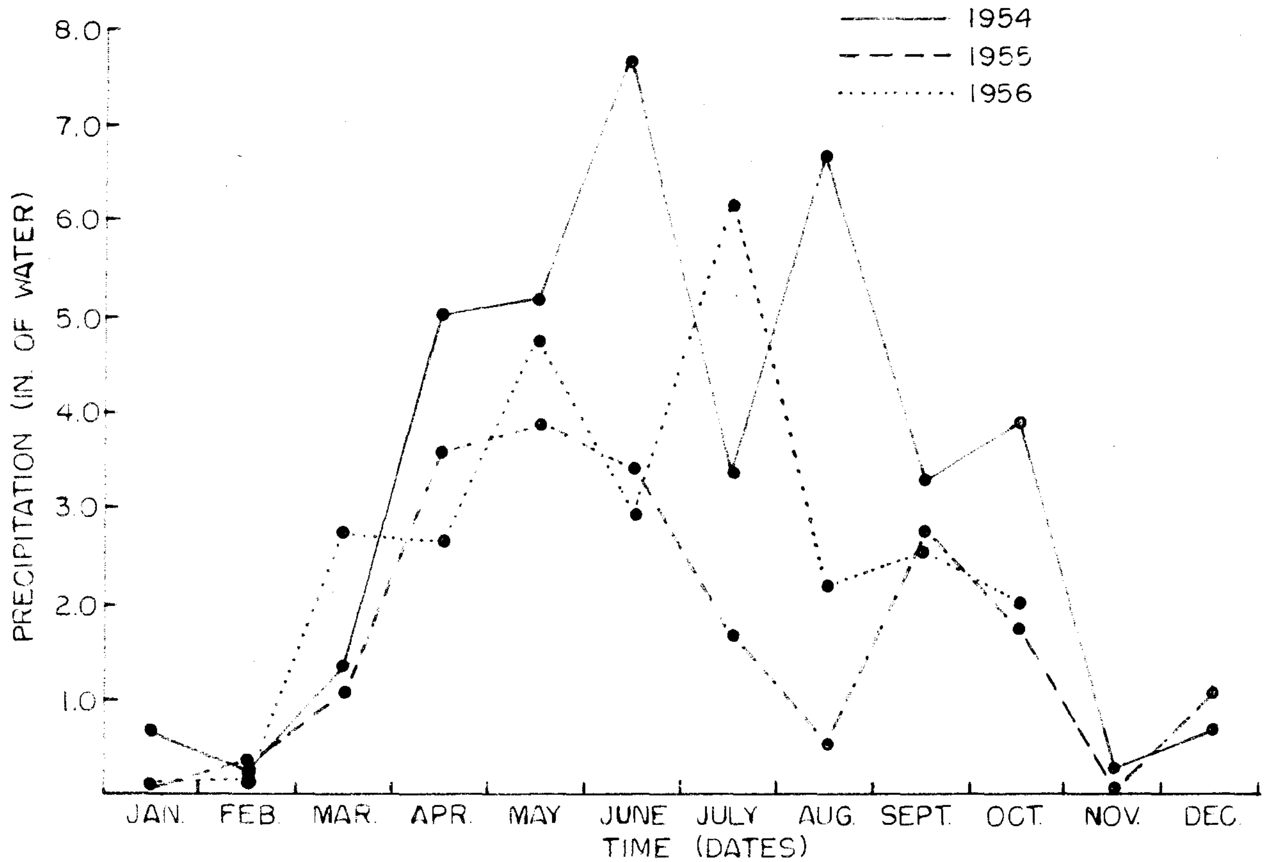
difference between the daily maximum and minimum temperature was smaller in the unburned areas until June, after which date the difference was about the same.

Average monthly temperatures for 1954, 1955, and 1956, as well as long-time monthly averages, are presented in Table 29. During the 1955 growing season the average monthly temperature was considerably higher than the long-time average except for June, while during the 1956 growing season the average temperature for each month was close to or below the long-time average.

Precipitation. The yearly precipitation based on long-time averages from the Cresco weather station is 31.90 inches (Table 29). The total precipitation for 1954 was 38.17 inches while it was only 20.11 inches for 1955. The summer of 1955 was very dry with only 2.18 inches of rain falling during July and August compared to a long-time average of 7.17 inches for these two months. Precipitation for the summer of 1956 was about average; that for July and August was above average. The total monthly precipitation for 1954, 1955, and 1956 is presented in Table 29. The bulk of the precipitation comes during the growing season, which is typical for a grassland climate (Figure 7).

Precipitation-evaporation ratios. The precipitation-evaporation ratio for the Hayden prairie area would be about 0.95 according to Transeau's map (108). This ratio, computed according to Thornthwaite's formula (98, 99) from long-time

Figure 7. Total precipitation in inches of water per month at the Saratoga weather station, four miles south of the Hayden prairie.


1954
1955
1956
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
PRECIPITATION (IN. OF WATER)
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
TIME (DATES)

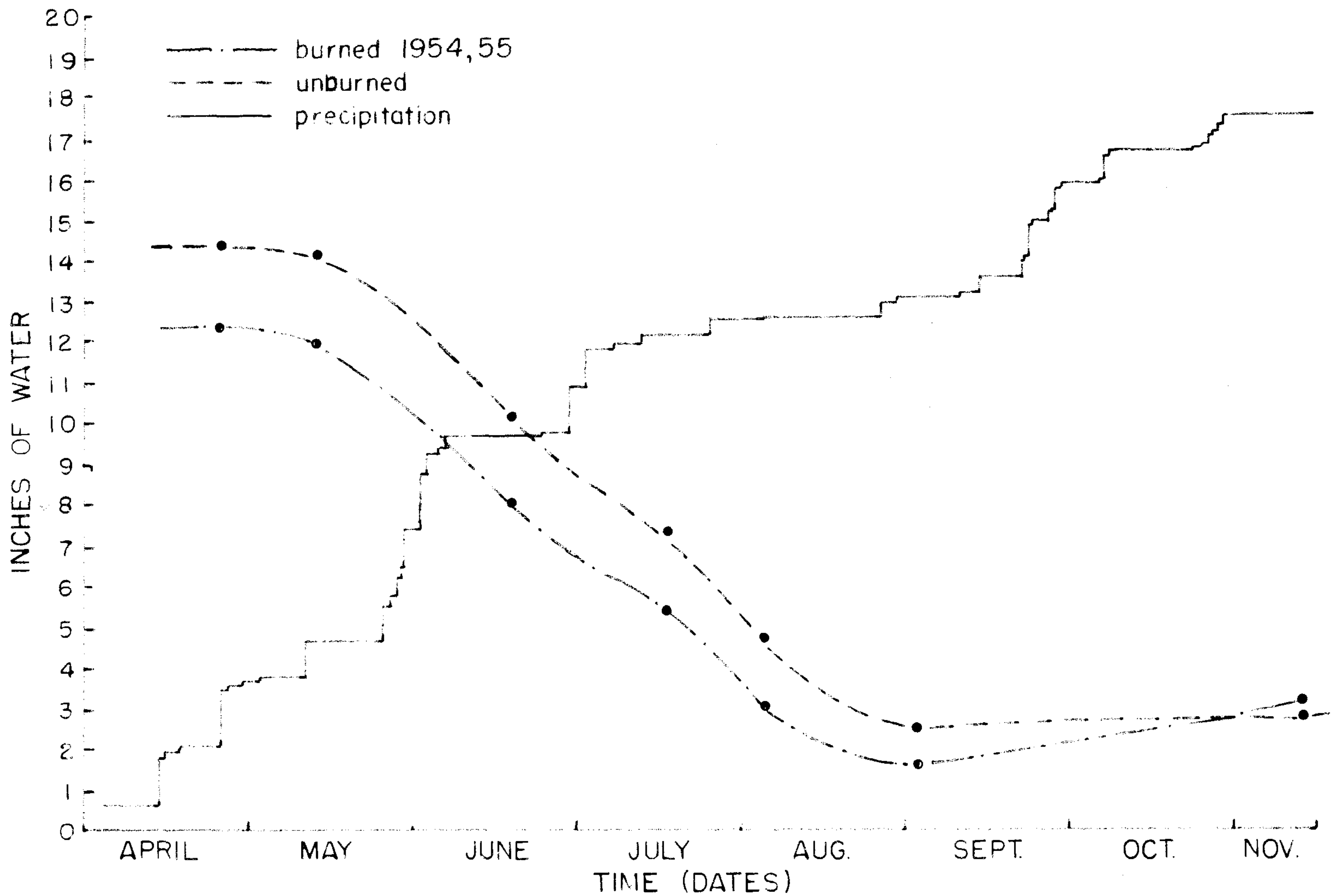
averages of precipitation and temperature at the Cresco weather station, was 0.89.

Precipitation-evaporation ratios for 1954 and 1955 computed by the same formula were 0.76 and 0.42, respectively. The variation of precipitation-evaporation ratios computed on a monthly basis was tremendous during 1954 and 1955. In 1954 the ratio varied from 1.40 in April to 0.13 during November and in 1955 it varied from 1.80 in December to 0.22 in August. The precipitation-evaporation ratio during the growing season (taken from April through September) was 0.88 for 1954, 0.52 for 1955, 0.58 for 1956, and 0.64 for the long-time average.

Soil data

Soil moisture. The precipitation received in the vicinity of the Hayden prairie during 1954 was considerably above normal (Table 29). As a result, the quantity of available moisture stored in the soil at the beginning of the 1955 growing season was large, ranging from 12.39 to 14.72 inches of available water in a four foot profile (Figure 8; Table 30). The soil was, in fact, very nearly saturated at this time. The rapid growth of vegetation in May and June depleted the soil moisture rapidly, in spite of good spring rains during the latter part of May, 1955. The below normal precipitation and the above normal temperatures during the summer of 1955 caused the available water in the four foot soil profile at the end of the summer to be very low. The depletion of soil moisture

Figure 8. Inches of available water in a four foot soil profile in burned and unburned areas of the Hayden prairie, and cumulative precipitation at the Saratoga weather station during 1955.

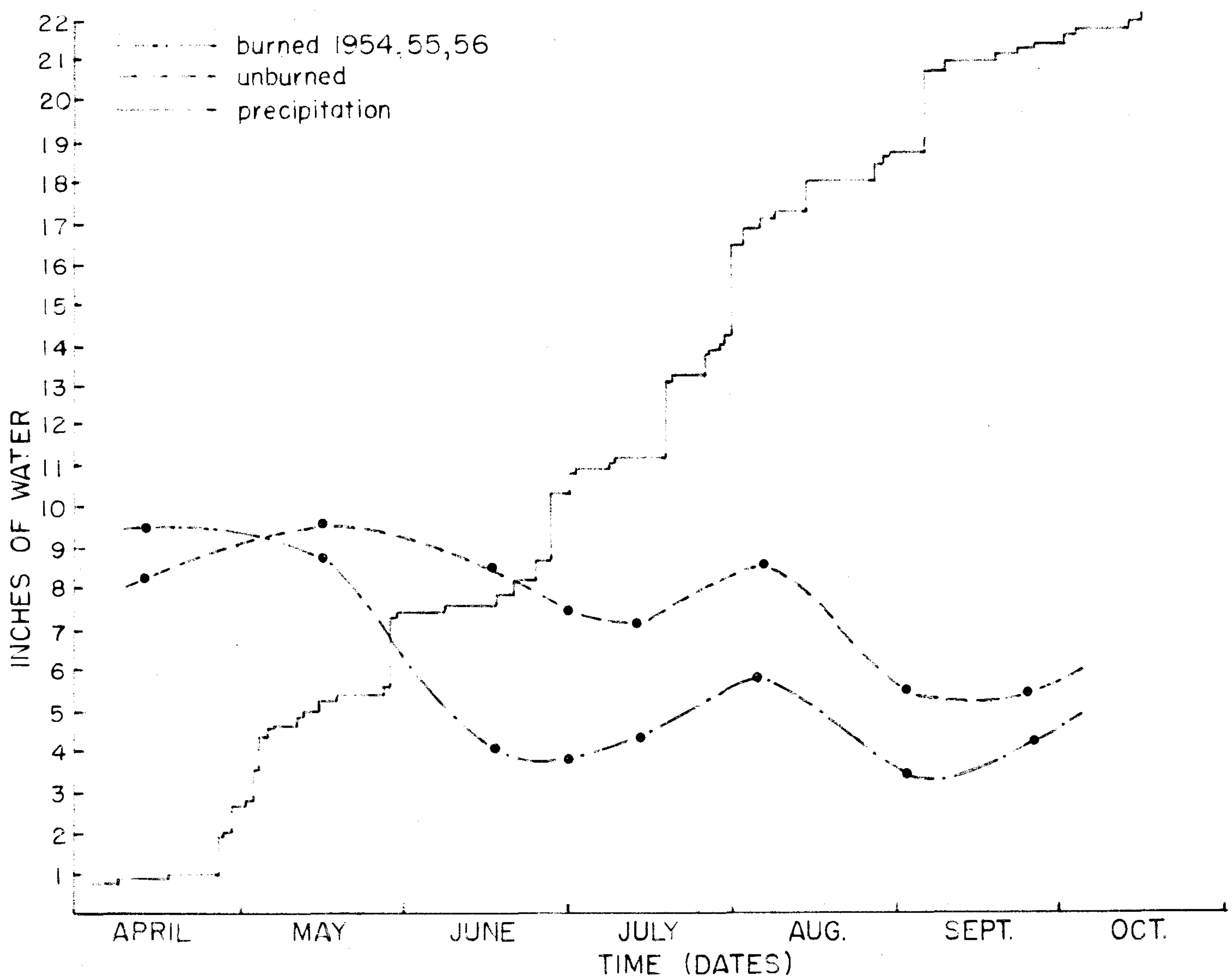


burned 1954,55
unburned
precipitation
INCHES OF WATER
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
TIME (DATES)

was greater on the burned than on the unburned areas (Figure 8; Table 30). In the top foot of soil on the burned areas, the soil moisture approached the permanent wilting percentage by midsummer (Table 33). The difference in soil moisture between the various burning treatments decreased toward the latter part of the growing season, and by the end of October, 1955, there was little difference in the amount of available moisture in the soil profiles of the treatments.

As a result of this severe depletion of soil moisture during the growing season of 1955, the amount of available water in the soil profile was considerably lower at the start of the 1956 growing season compared to the previous year, ranging from 8.18 to 9.45 inches of available water in a four foot profile (Figure 9; Table 31). The lower temperatures and greater precipitation during the 1956 growing season resulted in less severe depletion of soil moisture during the summer so that the total amount of available moisture in the four foot profile during 1956 did not reach the low point of the previous year. The rate of depletion of available soil moisture was much more rapid on the burned than on the unburned areas during 1956 (Tables 32 and 33). This resulted in a larger difference between burned and unburned areas in amount of available water in the soil profiles during 1956 as compared to 1955. The greatest difference in 1956 occurred in June when the unburned area had twice as much available water in the four foot profile as the 1954, 1955, and 1956 burned

Figure 9. Inches of available water in a four foot soil profile in burned and unburned areas of the Hayden prairie, and cumulative precipitation at the Saratoga weather station during 1956.


burned 1954,55,56
unburned
precipitation
INCHES OF WATER
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
TIME (DATES)

area (Figure 9; Table 31). In all of these results the more recent and severe burning treatments were more sharply contrasted to the unburned areas than the other burning treatments, which were more intermediate between the extremes. The statistical analysis of both 1955 and 1956 soil moisture data showed a significant difference between burning treatments (Tables 34 and 35).

The permanent wilting percentages of soil from various depths obtained from greenhouse determinations and the pressure membrane apparatus are presented in Table 2. The statistical analysis of both sets of data showed a highly significant difference between depths, and no significant difference between replications (Table 3). The pressure membrane apparatus gave slightly higher values for each depth, but the correlation coefficient between the two methods was .999.

The average field moisture percentage as determined from soil cores of upland prairie soil was 33.7 per cent moisture on an oven-dry weight basis for the 0-6 inch depth and 34.0 per cent for the same depth determinations using prairie sod in the laboratory. The average field moisture percentages for other depths down to 36 inches varied from these figures by no more than plus or minus 2.0 per cent.

Soil structure. Average values for volume weight, total pore space, capillary pore space, and large pore space measured in 1955 on 1954, 1955 burned, 1954 burned, 1955 burned and un-

Table 2. Permanent wilting percentage of soil from various depths as determined by the greenhouse method and by the pressure membrane apparatus[a]

Depth in inches	Percentage water on oven-dry basis	
	Greenhouse method	Pressure membrane apparatus
0-6	17.2	18.1
6-12	14.3	14.5
12-24	12.4	12.7
24-36	11.2	12.1
36-48	10.9	11.9

[a]Values for greenhouse method are averages of three replicates.
Values of pressure membrane apparatus are averages of two replicates.

Table 3. Analysis of variance of permanent wilting percentage determinations

Method	Source of variation	Degrees of freedom	Mean square
greenhouse	replications	2	0.03
	depths	4	19.09[a]
pressure membrane apparatus	replications	1	0.02
	depths	4	14.45[a]

[a]Significant at the 1% level.

burned areas are presented in Table 4. No statistically significant differences due to the burning treatments were demonstrated in these soil properties (Table 5). There was, however, a significant difference between depths for each soil

Table 4. Volume weights and pore space percentages of soil at depths of 0 to 1.5 and 3 to 4.5 inches for various burning treatments, 1955[a]

Treatment	Depth	Volume weight	Percentage large pore space	Percentage capillary pore space	Percentage total pore space
burned 1954, 55	0-1.5	0.688	27.5	46.6	74.1
	3-4.5	0.841	20.0	48.2	68.2
burned 1954	0-1.5	0.639	34.2	41.7	75.9
	3-4.5	0.826	17.8	50.6	68.4
burned 1955	0-1.5	0.644	35.1	40.6	75.7
	3-4.5	0.811	21.8	47.9	69.7
unburned	0-1.5	0.682	32.3	41.9	74.2
	3-4.5	0.811	22.1	47.3	69.4

[a]These values are averages of 12 replicates.

property measured. The total pore space in this upland prairie soil was about 75 per cent for the 0-1.5 inch depth and about 69 per cent for the 3-4.5 inch depth. The percentage capillary pore space was about 42 for the former depth and about 48 for the latter depth. The percentage large pore space was about 33 for the 0-1.5 inch depth and 21 for the 3-4.5 inch depth.

<u>Soil nutrients</u>. There was no great difference in the pH

Table 5. Analysis of variance for volume weights and pore space percentages, 1955

Physical	Source of variation	Degrees of freedom	Mean square
	locations	2	3.5
volume	treatments	3	6.8
weight	depths	1	630.2[a]
	locations	2	9.1
large pore	treatments	3	6.0
space	depths	1	102.0[a]
	locations	2	8.0
capillary	treatments	3	5.0
pore space	depths	1	84.0[a]
	locations	2	4.0
total pore	treatments	3	17.7
space	depths	1	2,303.0[a]

[a]Significant at the 1% level.

of the surface 0.75 inch of soil for the 1954,55 burned, 1954 burned, 1955 burned, and the unburned areas (Table 6). However, a slight increase in soil pH was noted on the 1954,55, 56 burned area and a considerable increase on the 1956 burned area. Burning of the large accumulation of organic material that existed on the latter area increased the pH of the surface soil to about 6.7, compared to 5.8 on an adjacent unburned area.

A very noteworthy effect was observed upon measuring available phosphorus (Table 6). The available phosphorus in pounds per acre for the top 0.75 inches of soil was 0.5 on the unburned areas, 1.0 on the 1954 burned and 1955 burned areas,

Table 6. The pH and nutrient determinations of the top 0.75 inch of soil from various burning treatments[a]

Treatment	pH	Nitrate nitrogen (lbs./acre)	Available phosphorus (lbs./acre)	Exchangeable potassium (lbs./acre)
burned 1954, 55, 56	6.1	48	3.0	348
burned 1954, 55	5.9	48	3.0	316
burned 1954	5.8	75	1.0	260
burned 1955	5.7	30	1.0	280
burned 1956	6.7	60	6.0	280
unburned	5.8	48	0.5	332

[a]These determinations were made by the Soils Testing Laboratory of Iowa State College from a composited sample of 24 sub-samples from various treatments.

and 6.0 on the 1956 burned area. Since the available phosphorus on the unburned area was very low, an increase of 12 times as noted on the 1956 burned area could have an important effect on the plants.

No important difference in production of nitrate nitrogen in the top 0.75 inch of soil was found. The values obtained on all treatments were in the "low" category. Since the samples were obtained about two months after the date of burning, it is possible that an earlier, ephemeral effect could have been detected by earlier sampling.

There was also no important difference in the exchangeable potassium in the top 0.75 inch of soil on the various burning treatments. The exchangeable potassium is high on all areas and would not be considered limiting.

Measurements of pH, production of nitrate nitrogen, available phosphorus, and exchangeable potassium were obtained from various depths on an 18 inch soil profile on 1954, 55, 56 burned and unburned areas (Table 7; Figures 10 and 11). The

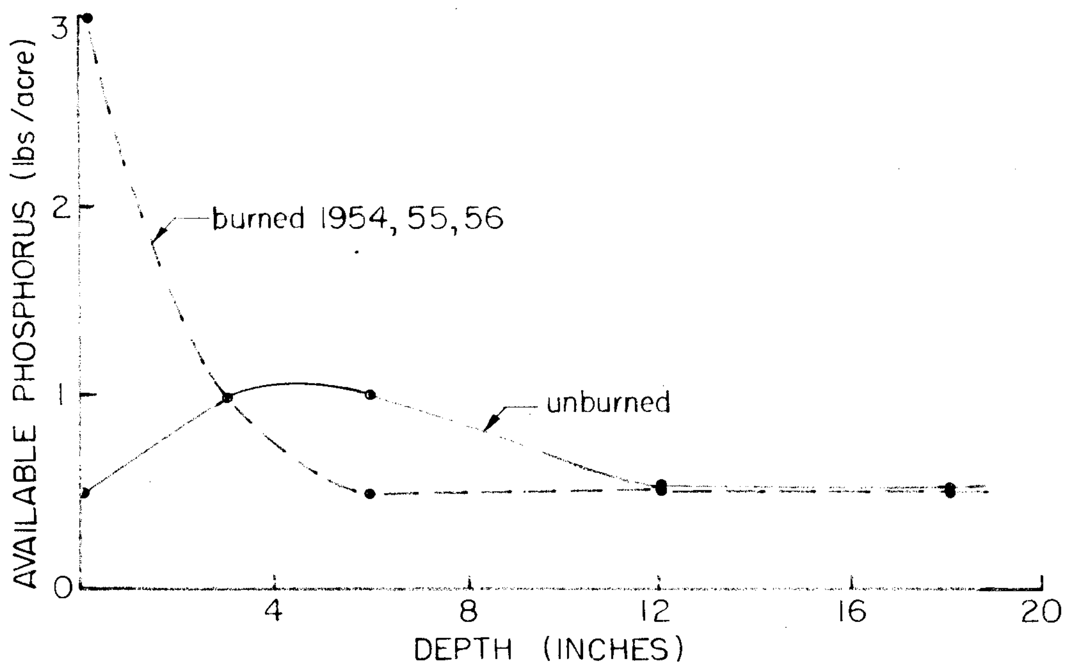
Table 7. The pH and nutrient determinations on soil from various depths in 1954, 55, 56 burned and unburned areas[a]

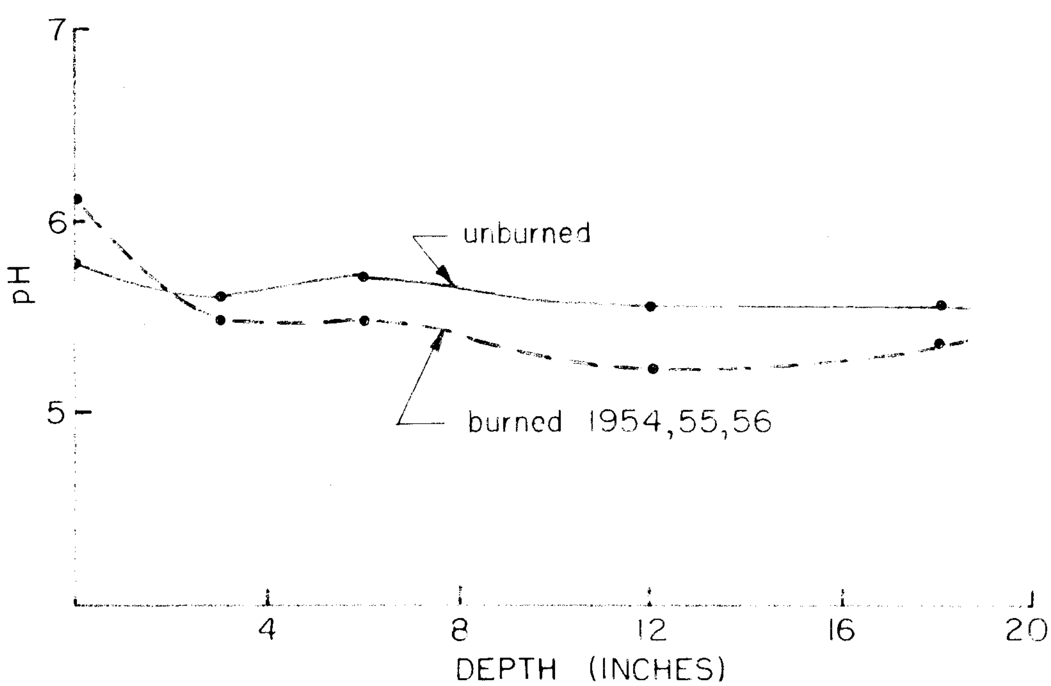
Treatment	Depth in inches	pH	Nitrate nitrogen (lbs./acre)	Available phosphorus (lbs./acre)	Exchangeable potassium (lbs./acre)
burned 1954,55,56	0-3/4	6.1	48	3.0	348
	3-4	5.5	21	1.0	172
	6-7	5.5	3	0.5	136
	12-13	5.4	1	0.5	120
	18-19	5.4	3	0.5	124
unburned	0-3/4	5.8	48	0.5	332
	3-4	5.7	27	1.0	160
	6-7	5.7	9	1.0	144
	12-13	5.6	3	0.5	120
	18-19	5.6	3	0.5	120

[a]These determinations were made by the Soils Testing Laboratory of Iowa State College from a composited sample of 24 subsamples from various treatments.

Figure 10. Available phosphorus with depth in soil profile on burned and unburned areas.

Figure 11. Soil pH with depth in soil profile on burned and unburned areas.


AVAILABLE PHOSPHORUS (lbs /acre)
0
1
2
3
burned 1954, 55, 56
unburned
4
8
12
16
20
DEPTH (INCHES)


pH
5
6
7
unburned
burned 1954, 55, 56
4
8
12
16
20
DEPTH (INCHES)

pH decreased slightly with depth on both areas. Production of nitrate nitrogen on both areas fell off quite rapidly with depth to an almost negligible figure at 18 inches. The amount of exchangeable potassium also decreased with depth, but not as rapidly. Available phosphorus in the top 0.75 inch of soil was higher on the 1954, 55, 56 burned area than on the unburned area. However, at the 4 to 9 inch depth the amount of phosphorus was greater on the unburned area. At lower depths there was little difference between the two areas.

The 1955 soil organic matter determinations using both the ignition and Schollenberger methods on various burning treatments indicated no significant difference in the amount of soil organic matter at either the 0-3 or 3-6 inch depths as a result of burning (Tables 8 and 9). Both methods of

Table 8. Percentage soil organic matter on various burning treatments using both the ignition and Schollenberger methods of determination, 1955[a]

Method	Depth (inches)	Burned 1954, 55	Burned 1955	Burned 1954	Unburned
ignition	0-3	11.0	11.6	10.5	11.2
	3-6	9.3	10.1	8.9	9.0
Schollen-berger	0-3	8.6	9.0	8.6	8.7
	3-6	7.1	7.1	6.7	6.6

[a]These values are averages of three replicates.

Table 9. Analysis of variance of soil organic matter determinations, 1955

Method	Source of variation	Degrees of freedom	Mean square
ignition	replications	2	2.0
	burning treatments	3	18.0
	depths	1	3,204.0[a]
Schollenberger	replications	2	1.0
	burning treatments	3	13.0
	depths	1	1,998.0[a]

[a]Significant at the 1% level.

determinations, however, indicated a highly significant difference in amount of organic matter among the depths measured. The ignition method of determination yielded values that were consistently higher than those obtained by using the Schollenberger method. A correlation coefficient of 0.98 was obtained for the results of the two methods.

Organic matter determinations made in 1956 by the ignition method showed no statistically significant difference between burning treatments in amount of soil organic matter at either the 0-3 or 3-6 inch depth. There was, however, a significant difference in the amount of soil organic matter between the two depths measured. Burning for as much as three consecutive years had no significant effect in the total amount of organic matter in the top six inches of soil (Tables 10 and 11).

Table 10. Percentage soil organic matter in soils exposed to various treatments, using the ignition method of determination, 1956[a]

Depth (inches)	Burned 1954,55, 56	Burned 1954,55	Burned 1954	Burned 1955	Burned 1956	Unburned
0-3	10.7	11.0	11.1	11.6	11.4	10.8
3-6	9.3	9.8	9.7	10.2	10.1	9.3

[a]These values are averages of three replicates.

Table 11. Analysis of variance of organic matter determinations by the ignition method, 1956

Source of variation	Degrees of freedom	Mean square
replications	2	2.33
burning treatments	5	2.32
depths	1	41.05[a]

[a]Significant at the 1% level.

Response of the vegetation

Plant growth. Because of the increased soil temperature on recently burned areas, the plants started growth in the spring at an earlier date and developed faster than plants in the unburned areas. In contrast to the green aspect of the burned areas in April, the unburned areas appeared brown, and the dry, dead vegetation of the previous year was matted down and intermingled with litter and duff. On areas burned the previous year and not the current year, the dead, dry vegetation was more erect and not even the leafy parts of the grasses were matted down to any great extent. Many dead seedstalks of some of the coarser grasses such as big bluestem, Indian grass, Canada wild rye, and some of the larger, more robust forbs such as compass plant, Baptisia, and meadow rue were still standing erect, bearing mute evidence to the lush growth of prairie vegetation on the burned areas of the previous year. Areas burned two years before had an appearance somewhat intermediate between the unburned areas and those areas burned a year previously and not the current year.

The prevernal aspect was markedly different on the burned and unburned areas. On the burned area, some of the early-growing forbs such as pasque-flower were in full bloom. Of the dominant grasses, porcupine grass, June grass, and Canada wild rye had made considerable growth, but were exceeded by the rapid development of bluegrass. In contrast, almost no forbs were blooming on the unburned area and the only grass that appeared very advanced in vegetative development was bluegrass.

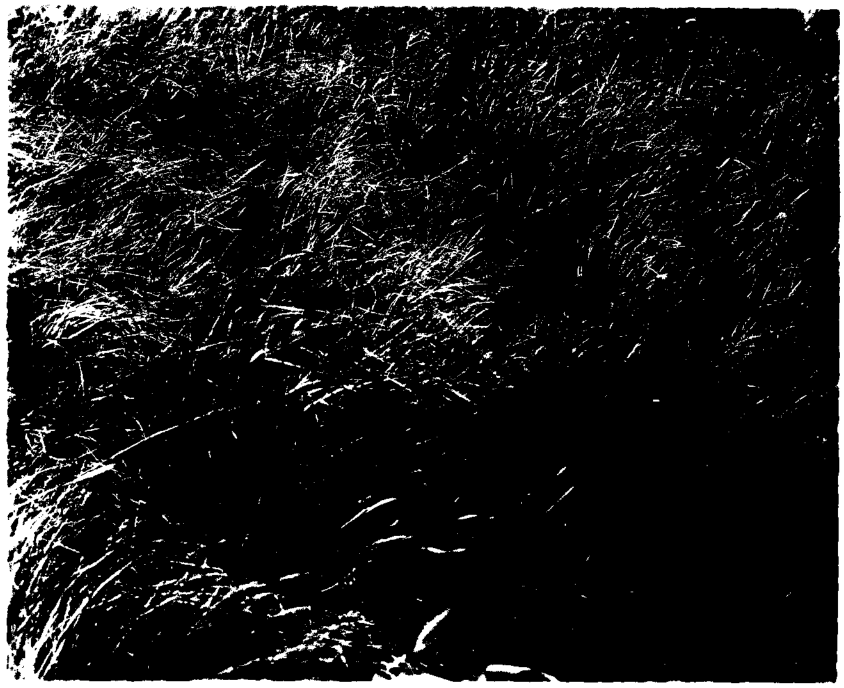
Late April introduced the vernal or spring aspect. During this period the recently burned areas were characterized by a profuse blooming of various forbs, initiation of flower stalks of bluegrass, and rapid vegetative growth of the dominant grasses. The yellow colors of *Zizia aurea* and

Lithospermum canescens, the pink and purples of *Phlox pilosa*, and the whites of *Baptisia leucantha* were sharply contrasted to the aspect of the unburned areas on which most of these forbs began blooming about two weeks later and were, in general, of smaller stature. In addition, considerably fewer of the forbs that were present on the unburned areas bloomed. The later development, the fewer flowers, and the dry, dead vegetation lent the unburned areas more of a drab appearance compared to that of the burned areas. Some of the plants found growing under the duff, were physically obstructed at least temporarily from pushing up through the matted organic material. Other plants growing under the duff had a yellowish-green appearance.

The estival or summer aspect began about the last week of May. By this time, on the burned areas, the bluegrass had completed flowering, the spikes of June grass were beginning to open, and porcupine grass was beginning to bloom. Some of the other dominants, such as the bluestems, were initiating flower stalks and had leaves 12 to 18 inches long. Myriads of flowers of many forbs contributed to a continued contrast of the burned and unburned areas (Figures 12 and 13). The greater number of purple flowers of *Amorpha canescens* and *Petalostemum purpureum*, the yellow flowers of *Solidago* spp. and *Coreopsis palmata*, and white flowers of *Achillea lanulosa* and *Galium boreale* among some forbs, accentuated this difference. The period of flowering and relative numbers of certain grasses

Figure 12. Late estival aspect of burned and unburned area, 1956. Unburned area showing mostly grasses in the vegetative condition with few flower stalks.

Figure 13. Late estival aspect of burned and unburned area, 1956. Area burned in 1954, 1955, 1956 showing flowerstalks of forbs and grasses.



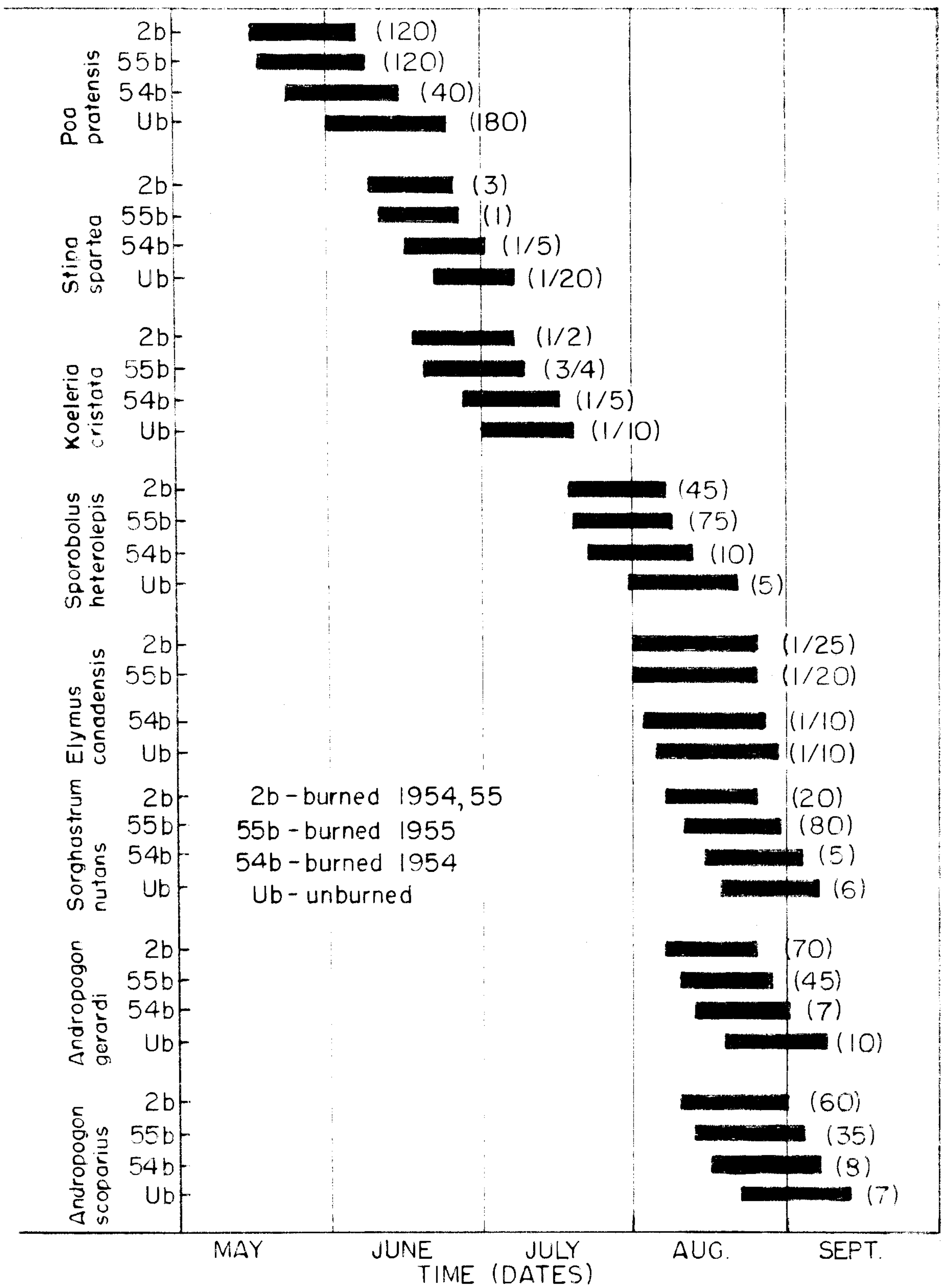
and forbs are presented in Figures 14 and 15.

Toward the end of the summer there was very little difference between the recently burned and the unburned areas in stage of development of a given species. However, there was still a great difference in size of most plants and in the number of seedstalks. The earlier and more abundant growth on the burned area the first growing season after burning, decreased the second and third growing seasons after burning, and the areas closely approached the general aspect of unburned areas.

Plant reproduction. A great difference was noted in the number and height of seedstalks of some of the important grasses. Four burning treatments in location 1 were compared as to percentage frequence, percentage abundance of seedstalks, and frequence x abundance values of key prairie species (Table 12). The frequence x abundance index total in 1956 for big bluestem, little bluestem, Indian grass, and prairie dropseed was 54.1 for the 1954, 55, 56 burned area, 13.6 for the 1954, 55 burned area, 8.2 for the 1954 burned area, and only 2.2 for the unburned area. The index totals for the three introduced grasses, bluegrass, timothy, and redtop showed a trend in the opposite direction: 16.5 for the 1954, 55, 56 burned area, 33.3 for the 1954, 55 burned area, 46.3 for the 1954 burned area, and 78.8 for the unburned area (Table 12).

Similar measurements made on a 1956 burned and an adjacent unburned area showed a frequence x abundance index

Figure 14. The effect of various burning treatments upon the period of anthesis and the number of plants per 100 ft.^{2} of Poa pratensis and some dominant grasses.



Poa pratensis
2b (120)
55b (120)
54b (40)
Ub (180)
Stipa spartea
2b (3)
55b (1)
54b (1/5)
Ub (1/20)
Koeleria cristata
2b (1/2)
55b (3/4)
54b (1/5)
Ub (1/10)
Sporobolus heterolepis
2b (45)
55b (75)
54b (10)
Ub (5)
Elymus canadensis
2b (1/25)
55b (1/20)
54b (1/10)
Ub (1/10)
Sorghastrum nutans
2b (20)
55b (80)
54b (5)
Ub (6)
Andropogon gerardi
2b (70)
55b (45)
54b (7)
Ub (10)
Andropogon scoparius
2b (60)
55b (35)
54b (8)
Ub (7)
2b - burned 1954, 55
55b - burned 1955
54b - burned 1954
Ub - unburned
MAY
JUNE
JULY
AUG.
SEPT.
TIME (DATES)

Figure 15. The effect of various treatments upon the period of anthesis and the number of plants per 100 ft.^{2} of some principal forbs.

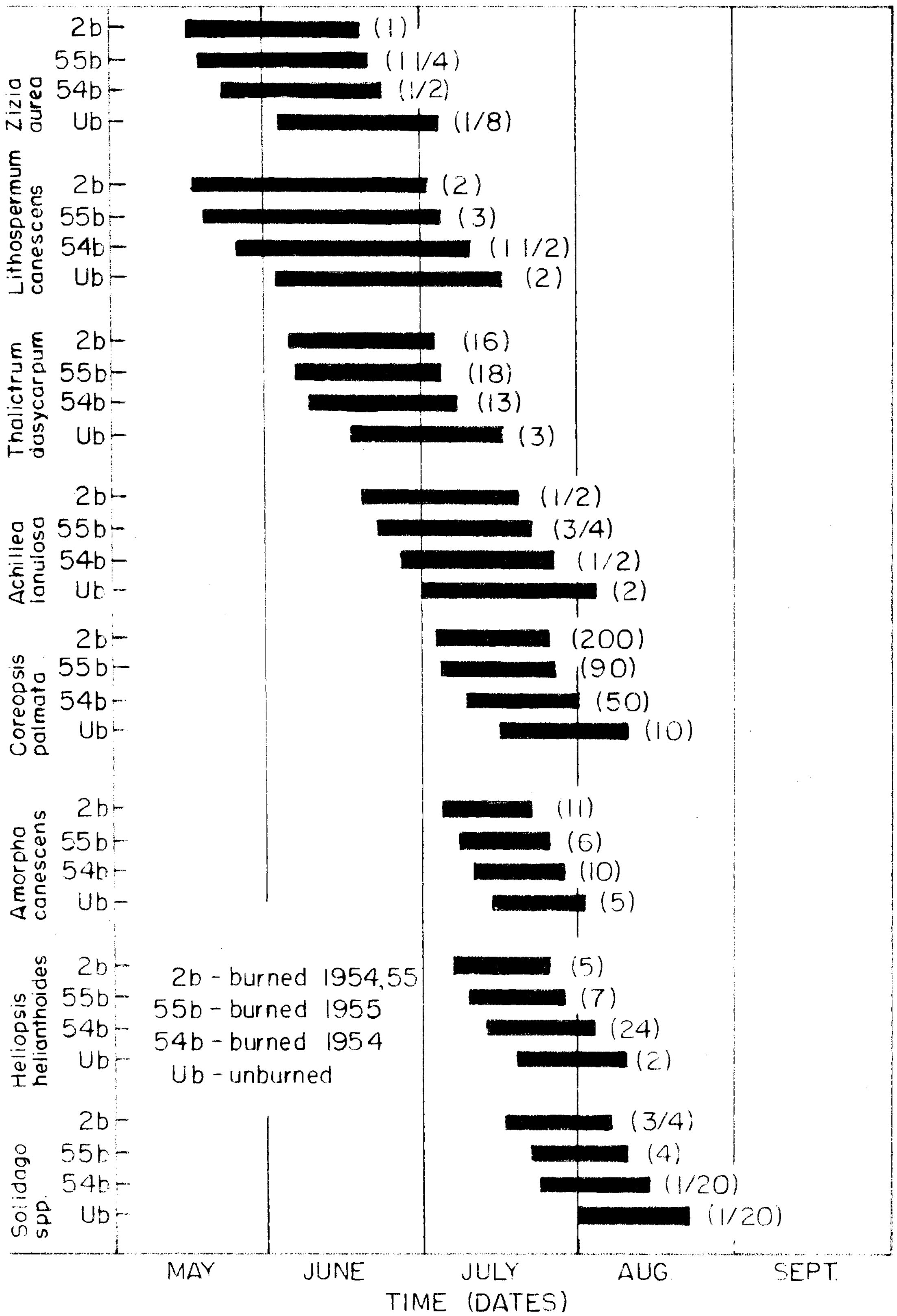

Zizia aurea
Lithospermum canescens
Thalictrum dasycarpum
Achillea lanulosa
Coreopsis palmata
Amorpha canescens
Heliopsis helianthoides
Solidago spp.
2b
55b
54b
Ub
(1)
(1 1/4)
(1/2)
(1/8)
(2)
(3)
(1 1/2)
(2)
(16)
(18)
(13)
(3)
(1/2)
(3/4)
(1/2)
(2)
(200)
(90)
(50)
(10)
(11)
(6)
(10)
(5)
(5)
(7)
(24)
(2)
(3/4)
(4)
(1/20)
(1/20)
2b - burned 1954, 55
55b - burned 1955
54b - burned 1954
Ub - unburned
MAY
JUNE
JULY
AUG.
SEPT.
TIME (DATES)

Table 12. Percentage frequence (% F.), percentage abundance (% A.), and frequence x abundance index (FxA) based on number of seedstalks of important grasses after various burning treatments, 1956[a]

Species	Burned, 1954,55,56			Burned 1954,55			Burned 1954			Unburned		
	% F.	% A.	FxA	% F.	% A.	FxA	% F.	% A.	FxA	% F.	% A.	FxA
big bluestem	75	15	11.3	50	13	6.5	50	10	5.0	40	3	1.2
little bluestem	90	39	35.1	35	8	2.8	30	6	1.8	30	2	0.6
Indian grass	50	5	2.8	35	10	3.5	30	4	1.2	15	1	0.2
Prairie dropseed	35	14	4.9	25	3	0.8	10	2	0.2	20	1	0.2
Kent. bluegrass	30	1	0.3	60	10	6.0	65	28	18.2	100	55	55.0
timothy	50	4	2.0	30	3	0.9	60	19	13.1	45	3	1.4
redtop	80	17	13.6	60	44	26.4	60	25	15.0	70	32	22.4
muhley grass	35	2	0.7	0	0	0	0	0	0	0	0	0
June grass	15	1	0.2	0	0	0	0	0	0	0	0	0
Carex spp.	45	2	0.9	40	8	2.6	30	6	1.8	10	1	0.1

[a]These values are from randomly located quadrates from each area. Percentage frequence is the percentage of quadrates that contain at least one seedstalk. Percentage abundance is the number of seedstalks of a particular species in all 20 quadrates divided by the total number of seedstalks of all species in all 20 quadrates times 100.

total of 73.8 for big bluestem, little bluestem, Indian grass, prairie dropseed, and Canada wild rye on the burned area and only 8.3 on the unburned areas. The index total for bluegrass, timothy, and redtop was 6.9 on the 1956 burned area and 79.3 on the unburned area (Table 13). In addition, average heights

Table 13. Percentage frequence (% F.), percentage abundance (% A.), and frequence x abundance index (FxA) based on number of seedstalks of important grasses on 1956 burned and unburned areas, 1956[a]

Species	Burned 1956			Unburned		
	% F.	% A.	FxA	% F.	% A.	FxA
big bluestem	100	40	40.0	65	5	3.3
little bluestem	75	17	12.8	50	4	2.0
Indian grass	65	6	3.9	55	5	2.8
prairie dropseed	80	1	16.1	5	0	0
Canada wild rye	25	7	0.3	15	1	0.2
Kent. bluegrass	80	1	5.6	100	78	78.2
timothy	40	3	0.4	25	1	0.3
redtop	30	3	0.9	25	3	0.8
Carex spp.	0	0	0	20	2	0.4
muhley grass	30	2	0.6	0	0	0
slender wheatgrass	15	1	0.2	15	1	0.2

[a]These values are from 20 randomly located quadrates from each area. Percentage frequence is the percentage of quadrates that contain at least one seedstalk. Percentage abundance is the number of seedstalks of a particular species in all 20 quadrates divided by the total number of seedstalks of all species in all 20 quadrates times 100.

of seedstalks were found to be from 10 to 20 per cent greater on all areas the first year after burning (Figure 16).

Frequence x abundance measurements taken on an area burned and mowed in 1955 and an adjacent 1955 burned and unmowed area showed greater numbers of seedstalks of the dominant grasses on the former and greater numbers of seed-stalks of introduced grasses on the latter (Table 14).

Three bundles of each of five key grasses, five square inches in cross sectional area, were taken from the 1956 burned and an adjacent unburned area. Measurements made on the seedstalks, seeds, leaves, and sheaths are presented in Table 15. The number of seedstalks per bundle was considerably greater on the 1956 burned area for all grasses except Canada wild rye, which had essentially no difference between the 1956 burned and unburned areas (Figures 17 and 18). The average height of seedstalks was about 25 per cent greater on the 1956 burned area for all grasses except Canada wild rye (Figure 18). The number of seeds per bundle was considerably greater from the 1956 burned area. The germination percentage was very low in all cases but generally higher from the burned than the unburned area. There was essentially no difference for any species in length of leaves from burned and unburned areas, however, the total weight of leaves per bundle from the unburned area was greater than from the burned area for all species except Canada wild rye and little bluestem. The amount of leaf area was directly related to the weight of

Figure 16. Late estival aspect of an area burned in the spring of 1956 and an adjacent unburned area.

Upper: Unburned area to left and foreground and burned area to right, background. Note greatly increased number of seedstalks of dominant grasses on burned area.

Lower: Close-up view of burned area showing greatly increased number of seedstalks of dominant grasses. The seedstalks showing above the skyline are mostly big bluestem and Indian grass (about 6 feet tall).

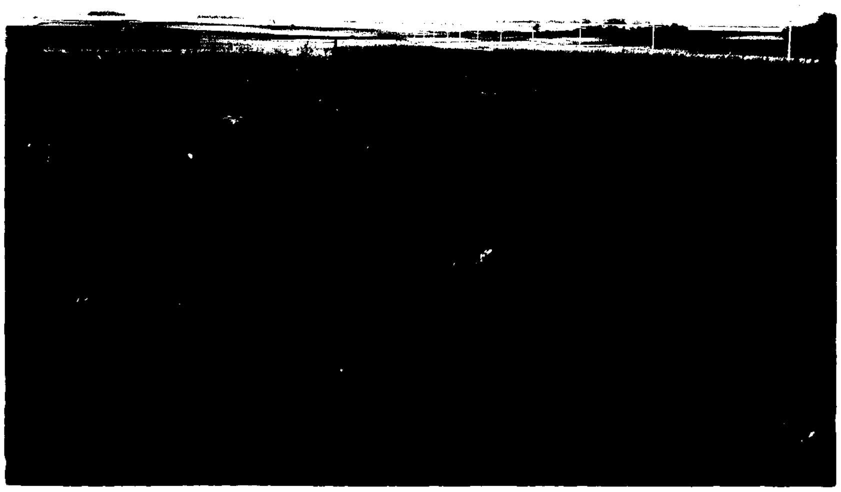


Table 14. Percentage frequence (% F.), percentage abundance (% A.), and frequence x abundance index (FxA) based on number of seedstalks of important grasses on a 1955 burned and mowed area and a 1955 burned and unmowed area, 1956[a]

Species	Burned and mowed 1955			Burned and unmowed 1955		
	% F.	% A.	FxA	% F.	% A.	FxA
big bluestem	100	48	48.0	70	18	12.6
little bluestem	60	20	12.0	40	4	1.6
Indian grass	40	1	0.4	20	2	0.4
prairie dropseed	40	5	2.0	10	1	0.1
Kent. bluegrass	100	10	10.0	70	21	14.7
timothy	60	3	1.8	30	3	0.9
redtop	50	9	4.5	70	42	29.4
Carex spp.	50	2	1.0	70	9	6.3
slender wheatgrass	20	1	0.2	0	0	0
June grass	20	1	0.2	0	0	0

[a]These values are from 20 randomly located quadrates from each area. Percentage frequence is the percentage of quadrates that contain at least one seedstalk. Percentage abundance is the number of seedstalks of a particular species in all 20 quadrates divided by the total number of seedstalks of all species in all 20 quadrates times 100.

Table 15. Relative production (dry weight) of various plant parts of certain dominant prairie species on burned and unburned areas, 1956

Plant part	Measurement	Big bluestem		Little bluestem		Indian grass		Prairie dropseed		Canada wild rye	
		1956 burn	unburn	1956 burn	unburn	1956 burn	unburn	1956 burn	unburn	1956 burn	unburn
seed-stalks	no./5 sq. inch bundle	54	8	350	41	74	33	101	13	105	102
	average height (in.)	56	36	32	24	56	36	43	30	46	46
	weight (grams)	76.5	8.2	36.7	9.3	70.8	18.0	31.7	0.5	113.5	111.0
fruits	no./5 sq. inch bundle	6440	560	11200	1500	7600	2320	3650	250	8200	8300
	weight (grams)	16.2	1.4	22.6	3.0	18.9	5.8	7.3	0.3	45.5	49.4
	per cent purity	10.4	7.6	16.5	0	6.4	1.9	76.2	46.3	40.1	47.9
	per cent germination	9.0	2.0	17.0	0	7.0	5.0	0	0	8.0	44.0
	no. viable seeds	61	1	314	0	34	2	0	0	262	1750
leaves	average length (in.)	20	18	17	17	22	20	26	24	18	18
	weight (grams)	47.4	61.8	35.6	36.6	47.8	57.6	50.1	92.3	52.0	47.4
	area/5 sq. inch bundle	4864	6622	4351	4473	4492	5419	5010	9230	4702	4256
sheaths	average length (in.)	5	4	3	3	8	6	12	9	6	6
	weight (grams)	36.2	16.0	23.2	7.8	52.1	24.0	37.3	10.4	47.3	48.2
total	weight (grams)	176.3	87.4	118.1	56.7	189.6	105.4	126.4	103.5	258.3	256.0

Figure 17. Samples of dominant grasses from an area burned in 1956 and an adjacent unburned area.

Left: The grasses from left to right are big bluestem from burned area, big bluestem from unburned area, Indian grass from burned area, Indian grass from unburned area.

Right: The grasses from left to right are prairie dropseed from burned area, prairie dropseed from unburned area, little bluestem from burned area, little bluestem from unburned area.

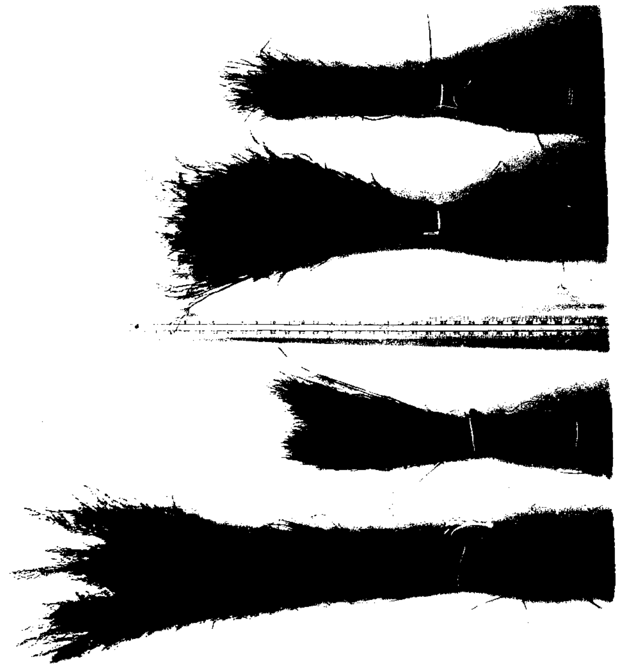
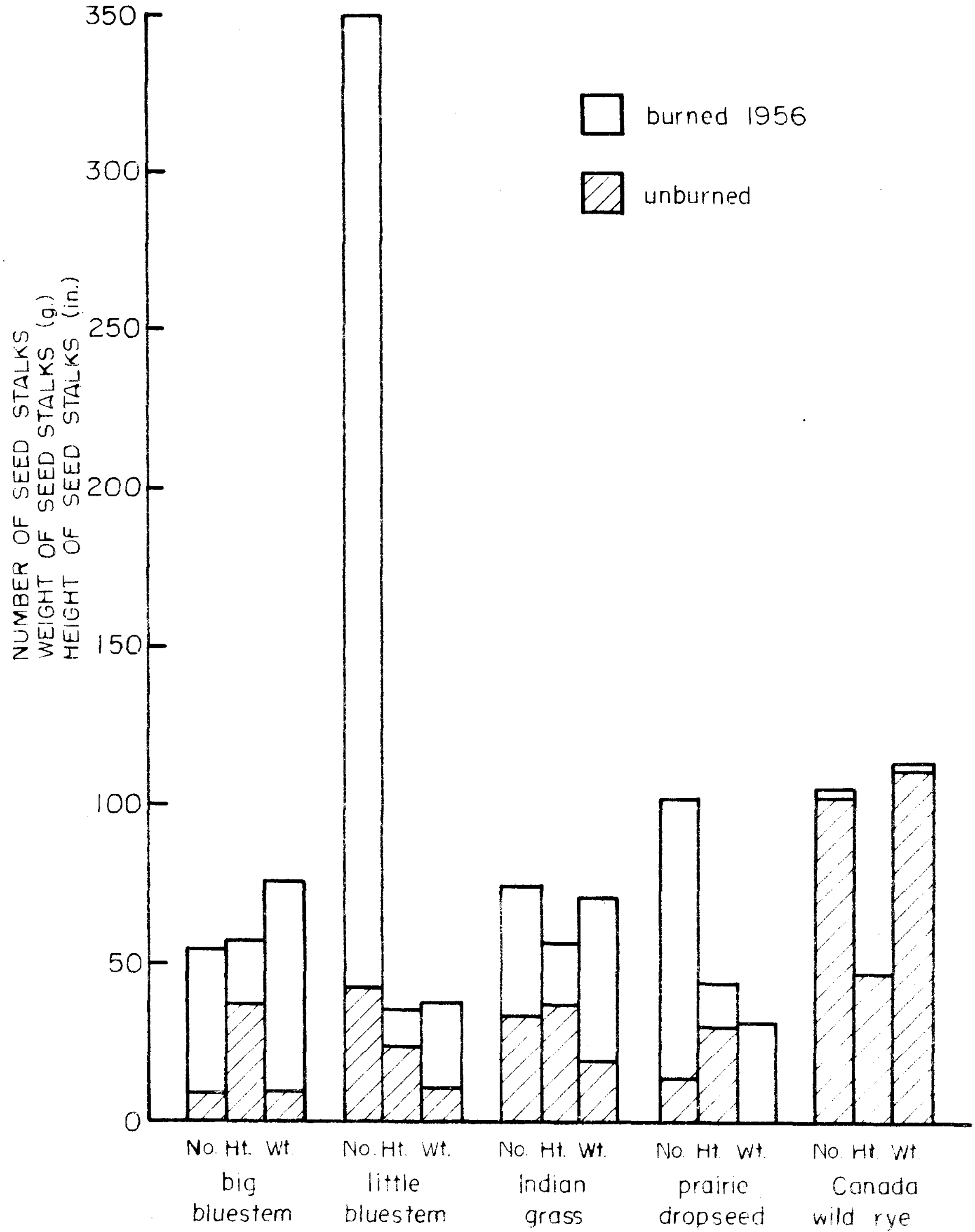


Figure 18. Number, total weight, and average height of seedstalks per bundle (5 $in.^2$ in cross section) of some dominant grasses on 1956 burned and unburned areas.



NUMBER OF SEED STALKS
WEIGHT OF SEED STALKS (g.)
HEIGHT OF SEED STALKS (in.)
0
50
100
150
200
250
300
350
burned 1956
unburned
No. Ht. Wt.
big bluestem
No. Ht. Wt.
little bluestem
No. Ht. Wt.
Indian grass
No. Ht. Wt.
prairie dropseed
No. Ht. Wt.
Canada wild rye

leaves. The total weight of the bundles from the 1956 burned area was greater than those from the unburned area for all species except Canada wild rye (Figure 19). In general, the Canada wild rye did not exhibit any of the differences in production of plant parts noted in the other species from burned and unburned areas.

Yield. The 1955 clipping data revealed that the yield from plots clipped near the end of the growing season were significantly greater on all treatments than the total yield from plots clipped four times during the growing season (Table 16, Figure 20). The total yield from seasonal clippings on the recently burned areas (1954, 55 burned and 1955 burned areas) was more than 0.5 ton per acre (32 per cent)

Table 16. Yields in tons per acre from plots clipped four times during the season and plots clipped at the end of the growing season, 1955[a]

Treatment	Date				Total yield from 4 clippings	Yield from 1 clipping
	May 30	July 1	Aug. 4	Sept. 2		
unburned	0.282	0.546	0.502	0.140	1.470	1.646
burned 1954	0.666	0.484	0.368	0.048	1.566	1.806
burned 1955	0.660	0.550	0.298	0.034	1.542	2.126
burned 1954,55	0.754	0.554	0.270	0.020	1.598	2.044

[a]These values are averages of 15 plots, 1/4000th acre each with the dry weight yields converted to tons per acre.

Figure 19. Dry weights of various plant parts per bundle (5 in.^{2} in cross section) of some dominant grasses from 1956 burned (A) and unburned (B) areas.

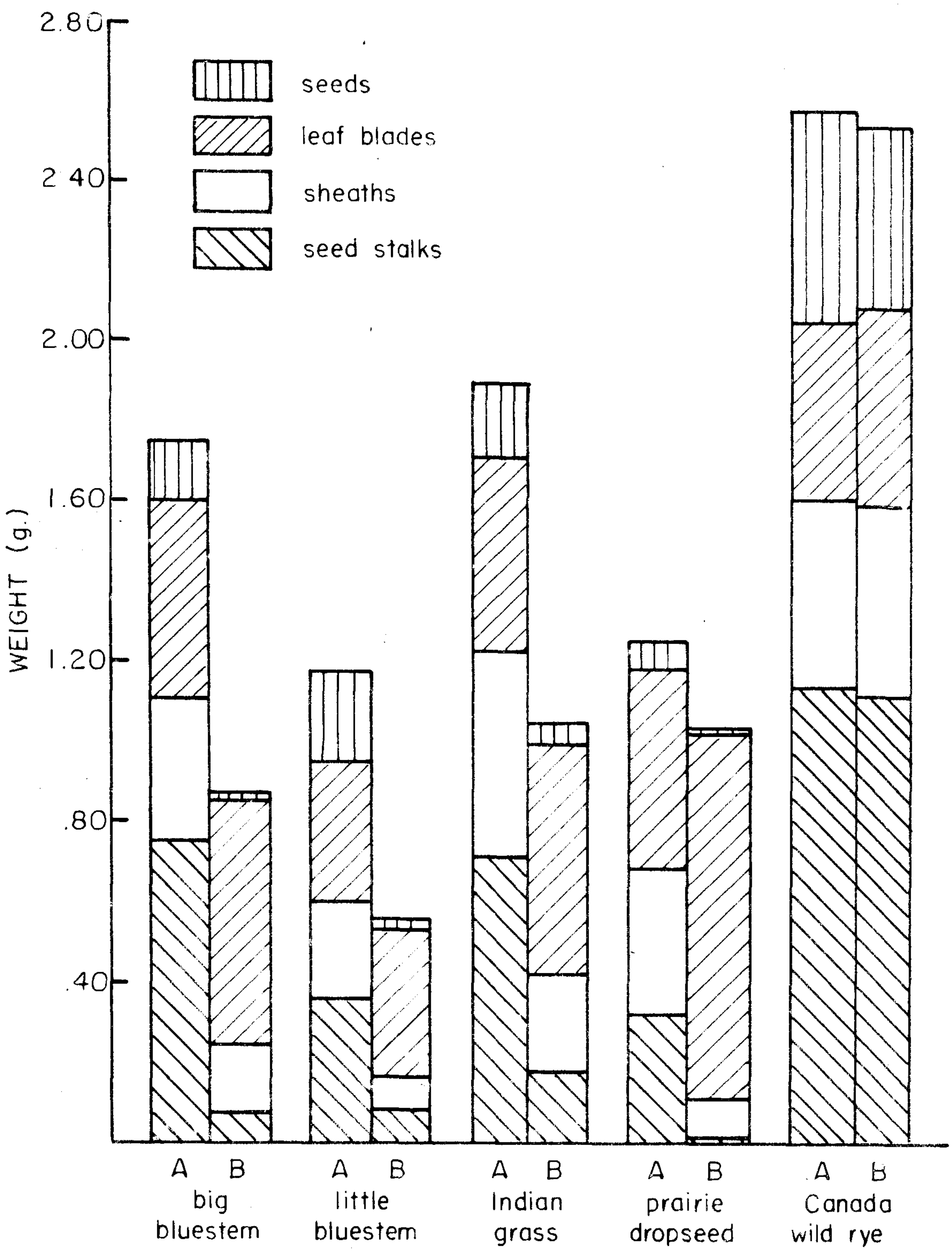
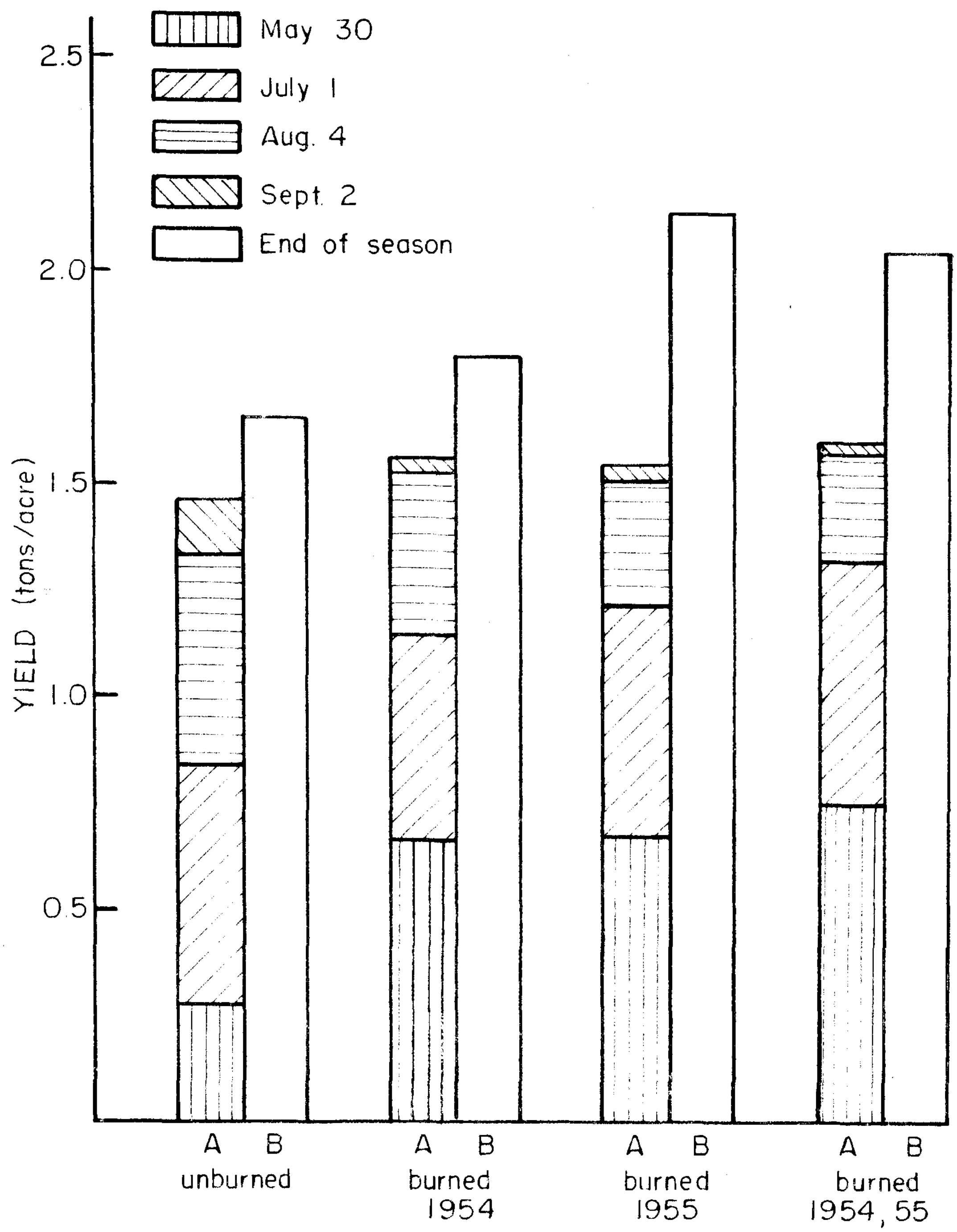

2.80
2.40
2.00
1.60
1.20
.80
.40
WEIGHT (g.)
seeds
leaf blades
sheaths
seed stalks
A B
big bluestem
A B
little bluestem
A B
Indian grass
A B
prairie dropseed
A B
Canada wild rye

Figure 20. Yields in tons per acre from plots clipped four times during the year (A), and plots clipped at end of the growing season (B), 1955.


May 30
July 1
Aug. 4
Sept. 2
End of season
2.5
2.0
1.5
1.0
0.5
YIELD (tons/acre)
A B
unburned
A B
burned
1954
A B
burned
1955
A B
burned
1954, 55

greater than the total yield of the four clippings. On the unburned and on the 1954 burned areas the yield from the seasonal clippings amounted to less than 0.2 ton per acre (14 per cent) greater than the total yield of the four clippings (Table 16). There was no statistically significant difference in yield due to the various burning treatments (Table 17).

Table 17. Analysis of variance of plots clipped once, at the end of the season, and totals of plots clipped four times during 1955.

Source of variation	Degrees of freedom	Mean square
location	2	52,558
burning treatment	3	120,068
methods of clipping	1	967,106[a]

[a]Significant at the 5% level.

However, there was a significant difference between the total yield from seasonal clippings and the total yield from the four clippings.

The yields obtained on the four different clipping dates in 1955 indicated that the vegetation on all burned areas was further along in development by May 30th, the first clipping date, than the vegetation on the unburned areas. On the burned areas, the greater yields were obtained the first two clipping dates, May 30 and July 1, while on the unburned areas the greater yields were obtained on the second and third clipping dates, July 1 and August 4. The statistical analysis indicated a highly significant difference for time of clipping and for the interaction of time of clipping and burning treatments (Table 18).

Table 18. Analysis of variance of plots clipped four different times during 1955

Source of variation	Degrees of freedom	Mean square
locations	2	338
burning treatments	3	562
time of clipping	3	169,773[a]
treatment x time	9	14,511[a]

[a]Significant at the 1% level.

The 1956 clipping studies conducted in locations 1 and 2 involved a comparison of plots clipped both seasonally and four times during the summer for the first year on the 1954, 55, 56 burned, 1954, 55 burned, 1954 burned, and on unburned areas. In addition, all plots in locations 1 and 2 on 1954, 55 burned, 1954 burned, and on unburned areas that were clipped during 1955, received similar clipping treatments during 1956. The former phase of the 1956 clipping studies showed results similar to those obtained during 1955 in that the seasonally clipped plots produced significantly more forage than plots clipped four times during the growing season (Tables 19 and 20; Figure 21). As in 1955, the 1956 clipping data showed no statistically significant differences between burning treatments. A statistical analysis of data from clippings of the various treatments at four different dates throughout the growing season indicated a significant difference in yields obtained at the various dates and a significant difference in the burning treatment and date of clipping interaction (Table 21). The 1956 results again showed a greater rate or degree of development on the more recently burned areas.

The latter phase of the 1956 clipping study was the comparison of plots clipped for the first and the second year. The analysis of variance of these data indicated a statistically significant difference between all plots clipped for the first year (both seasonal clipping and the total of those clipped four times during the growing season) and those that received similar clipping treatments for the second consecutive year (Table 22). The yields from plots clipped four times during the growing season for two years were lower in every case than the yields from plots similarly clipped for one year. There is also a statistically significant difference between yields from plots clipped seasonally, either for the first year or for two consecutive years, and the total yield

Table 19. Yields in tons per acre from plots clipped at four different dates during both 1955 and 1956, plots clipped at four different dates for the first year, plots clipped at the end of the growing season during both 1955 and 1956, plots clipped at the end of the growing season for the first year, and the percentage of the yield composed of grasses, 1956[a]

Treatment	June 15		July 13		August 4		September 2		Total yield 4 clippings		Yield from 1 clipping	
	yield	% grass	yield	% grass	yield	% grass	yield	% grass	yield	% grass	yield	% grass
unburned, 1 yr. of clipping	0.644	72	0.472	91	0.174	94	0.104	73	1.394	81	2.218	86
unburned, 2 yr. of clipping	0.774	92	0.272	95	0.076	97	0.044	82	1.166	92	1.800	86
burned, 1954 1 yr. of clipping	0.794	70	0.396	83	0.128	95	0.150	75	1.468	75	2.234	82
burned, 1954 2 yr. of clipping	0.946	77	0.224	90	0.066	94	0.034	81	1.270	80	1.894	80
burned, 1954, 55 1 yr. clipping	1.032	82	0.470	89	0.150	96	0.102	73	1.734	80	2.090	91
burned, 1954, 55 2 yr. clipping	0.898	85	0.260	90	0.052	96	0.022	73	1.234	87	1.958	88

[a]These values are averages of 10 plots, 1/4000th acre each, with the yields converted to tons per acre.

Table 19, (continued)

Treatment	June 15		July 13		August 4		September 2		Total yield 4 clippings		Yield from 1 clipping	
	yield	% grass	yield	% grass	yield	% grass	yield	% grass	yield	% grass	yield	% grass
burned, 1954, 55,56 1 yr. of clipping	1.024	65	0.392	92	0.098	97	0.050	84	1.564	73	1.796	70

Table 20. Analysis of variance of the 1956 clipping studies involving plots clipped for the first time near the end of the growing season and the total of those clipped four times during the season

Source of variation	Degrees of freedom	Mean square
locations	1	21,550
burning treatments	3	91,956
method of clipping	1	1,334,034[a]

[a]Significant at the 1% level.

Table 21. Analysis of variance of the 1956 clipping studies involving plots clipped at four different dates throughout the growing season for the first year

Source of variation	Degrees of freedom	Mean square
locations	1	62
burning treatments	3	7,691
time of clipping	3	288,853[a]
treatment x time	9	9,314[a]

[a]Significant at the 1% level.

Figure 21. Yields in tons per acre from plots clipped four times during the year for two consecutive years (A), plots clipped four times during the year for the first year (B), plots clipped at the end of the growing season for two consecutive years (C), and plots clipped at the end of the growing season for the first year (D). The percentage of the total yield composed of grasses in 1956 appears on top of each bar.

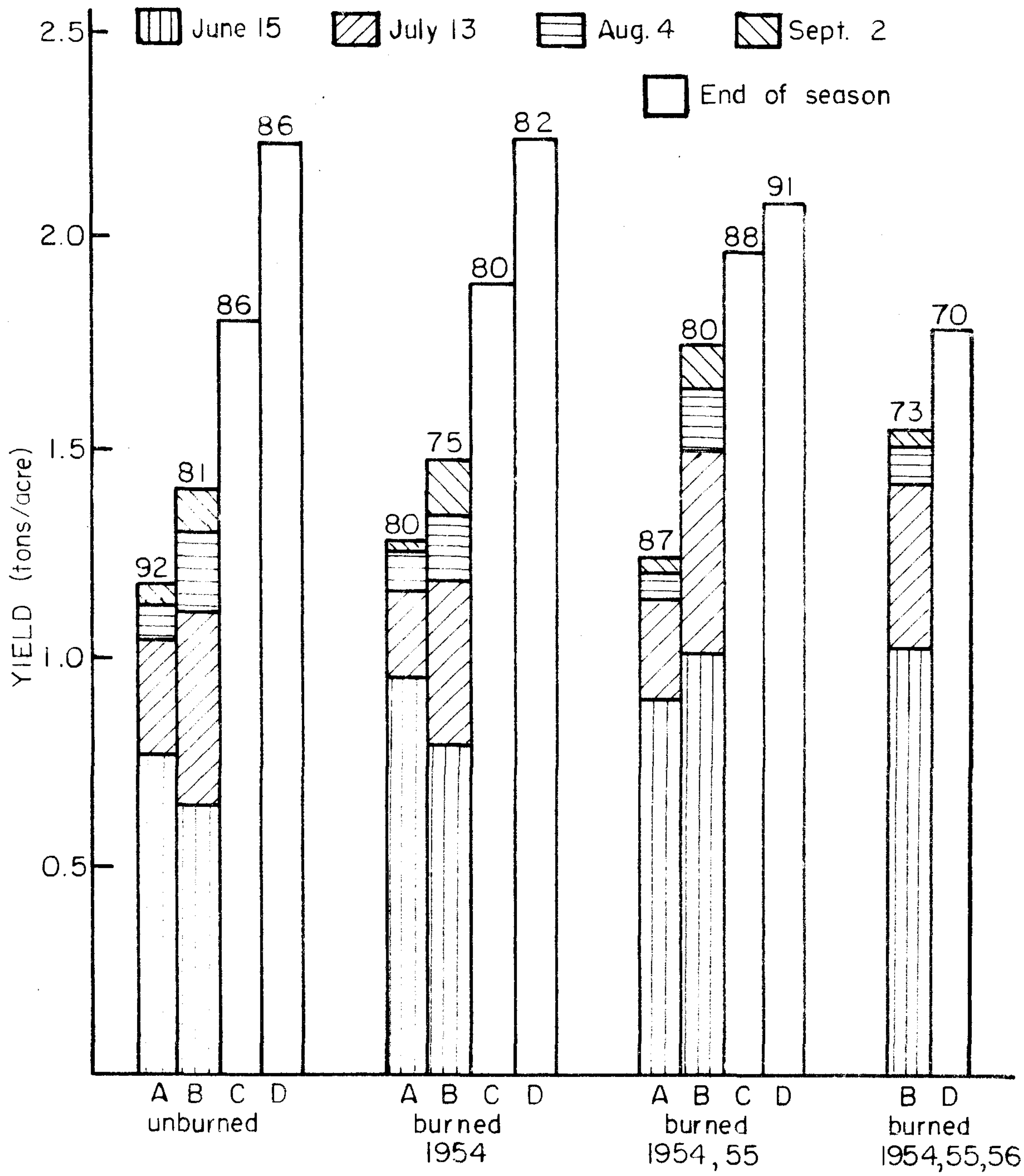

June 15
July 13
Aug. 4
Sept. 2
End of season
YIELD (tons/acre)
2.5
2.0
1.5
1.0
0.5
92
81
86
86
80
75
80
82
87
80
88
91
73
70
A B C D
unburned
A B C D
burned
1954
A B C D
burned
1954, 55
B D
burned
1954,55,56

Table 22. Analysis of variance of the 1956 clipping studies involving yields from plots clipped the first and the second year seasonally and the total of plots clipped at four different dates during the growing season for the first and the second year

Source of variation	Degrees of freedom	Mean square
locations	1	5,097
years of clipping	1	190,282[a]
burning treatments	2	10,106
method of clipping	1	605,155[a]

[a]Significant at the 1% level.

of plots clipped four times during the season for either the first year or the second year (Table 22). The yields from seasonal clippings were greater in every case than the total yields from plots clipped four times. For all burned and unburned areas, the 1956 yields were greatest from plots clipped at the end of the growing season for the first year. The next highest yields were from plots clipped at the end of the growing season for the second year followed by total yields from plots clipped at four different dates for the first year. The total yields from plots clipped four times during the growing season the second year were the lowest on all burned and unburned areas (Table 19, Figure 21).

A statistical analysis of 1956 yield data from plots frequently clipped for the first year and for the second consecutive year indicated a significant difference between yields from one and two years of frequent clipping and a significant difference between yields from various dates of clipping, but no significant difference of the interaction of these factors (Table 23). The yields obtained on the first of the four clipping dates on the frequently clipped plots (June 15) were greater from plots clipped for the second consecutive year than from plots clipped for the first year on 1954 burned and unburned areas and less from plots clipped for the second year on 1954, 55 burned areas. All yields from subsequent clipping dates fell off markedly and the yields from plots clipped frequently for two years were considerably lower on all treatments than plots clipped for the

Table 23. Analysis of variance of the 1956 clipping studies involving yields from plots clipped four times during the growing season for the first and the second year

Source of variation	Degrees of freedom	Mean square
locations	1	1,220
years of clipping	1	27,456[a]
burning treatments	2	6,530
time of clipping	3	416,703[b]
treatment x time	6	9,004

[a]Significant at the 5% level.

[b]Significant at the 1% level.

first year.

The yield of a 1956 burned area clipped at the end of the growing season was 2.55 tons per acre compared to 1.70 tons per acre on an adjacent unburned area. This amounted to an increase of 0.85 ton per acre or 50 per cent from the burning. This increase in yield, however, was caused mostly by an increase in seedstalk development of the dominant grasses on the burned area.

The yield obtained from clippings at the end of the 1956 growing season on a 1955 burned area that was mowed in August, 1955 was 2.11 tons per acre compared to 1.66 tons per acre for an adjacent 1955 burned area that was not mowed in 1955. The increase in yield was mostly due to a greater production of seedstalks by the dominant grasses on the burned and mowed area.

No statistically significant differences were demonstrated between percentages of yields composed of grasses and forbs for comparison of treatments, time or methods of clipping. The variation between plots was so great that no real differences could be seen.

Litter and duff measurements

The amount of litter and duff on unburned areas of the Hayden prairie had increased under protection until 1954 when the total amount equaled or exceeded the yearly yield of vegetation (2). The yield of litter and duff on these unburned areas was rather constant from 1954 to 1956. Thus the rate of accumulation was approximately equal to the rate of decay (Figure 22, Table 24a). A statistical analysis of data from each time of measurement showed a significant difference in amount of litter and duff on the various burning treatments (Table 24b). The amount of litter and duff on the various areas is related to the severity of the burning treatments (Figure 23).

The litter and duff measurements taken on the unburned area after mowing with commercial equipment in 1956 showed that the haying operations, while removing most of the current year's growth of vegetation, did not disturb the accumulated organic material to any great extent (Figure 24).

From the rate of litter and duff accumulation on the earlier burned areas, it was determined that about 0.70 tons per acre of duff was accumulated the first year after burning, 0.53 tons per acre the second year after burning, and 0.35 tons per acre the third year. Thus the rate of accumulation decreased by one-third to one-fourth of the previous year's accumulation. At this rate, it would take the 1954 burned area about four to six years to accumulate as much litter and duff as is found on the unburned areas (Figure 25).

Table 24a. Amount of litter and duff in tons per acre on various treatments measured for three different years[1]

Treatment	Time of measurement			
	spring 1954	spring 1955	spring 1956	fall 1956
unburned	2.28	2.18	2.20	1.40
burned 1954	0.28	0.98	1.51	0.99
burned 1955		0.40		
burned 1954,55		0.15	0.75	0.55
burned 1954,55,56			0.13	0.10
unburned and mowed				1.44

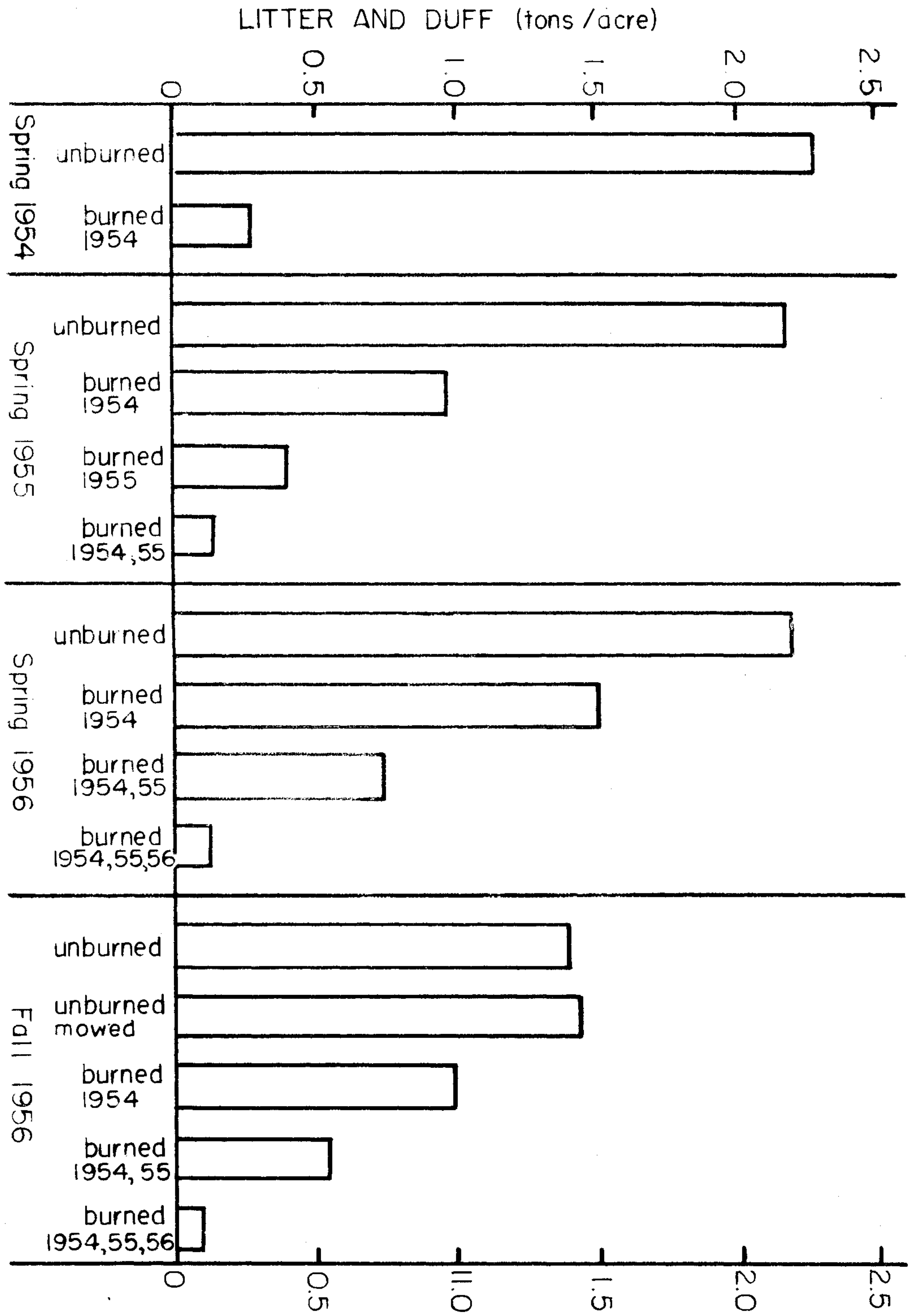
[1]These values are the averages of several replicates of 1/4000th acre plots. The 1954 data were taken from Aikman (2).

Table 24b. Analysis of variance of litter and duff data collected at three different times

Time taken	Source of variation	Degrees of freedom	Mean square
spring 1955	replications	3	0.2
	burning treatments	3	39.0[a]
spring 1956	replications	2	0.1
	burning treatments	3	24.0[a]
fall 1956	replications	2	0.1
	treatments	4	24.9[a]

[a]Significant at the 1% level.

Figure 22. Amount of litter and duff after various burning treatments for three different years.



LITTER AND DUFF (tons/acre)
0
0.5
1.0
1.5
2.0
2.5
Spring 1954
unburned
burned 1954
Spring 1955
unburned
burned 1954
burned 1955
burned 1954,55
Spring 1956
unburned
burned 1954
burned 1954,55
burned 1954,55,56
Fall 1956
unburned
unburned mowed
burned 1954
burned 1954, 55
burned 1954,55,56

Figure 23. Comparison of amount of litter and duff remaining on two burning treatments in the spring of 1955.

Upper: Area burned in 1955.

Lower: Area burned in 1954 and 1955.

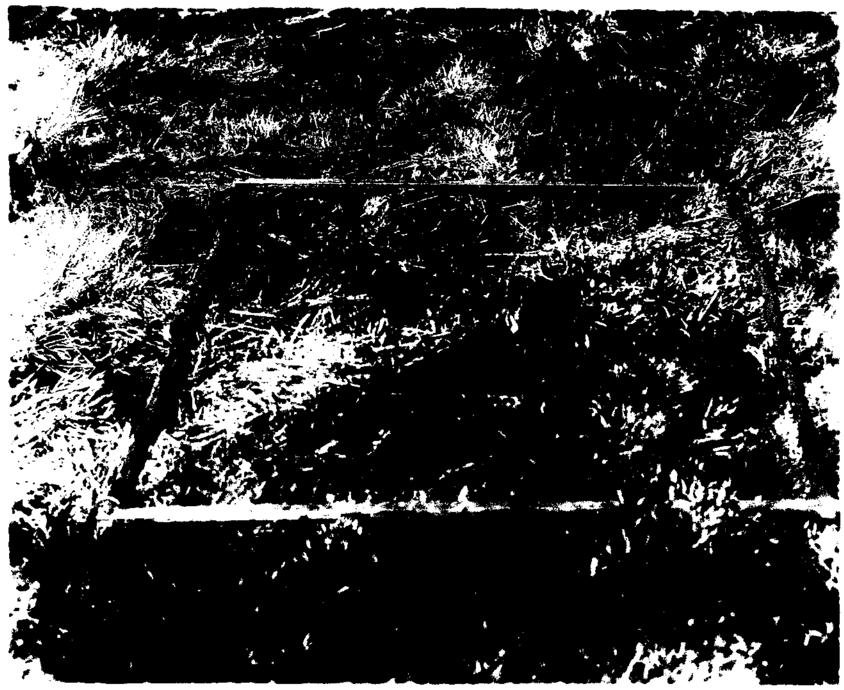


Figure 24. Comparison of litter and duff left on unburned areas under two methods of mowing, September, 1956.

Upper: A plot clipped four times a year for two consecutive years.

Lower: An area mowed with heavy commercial equipment at the end of the growing season.

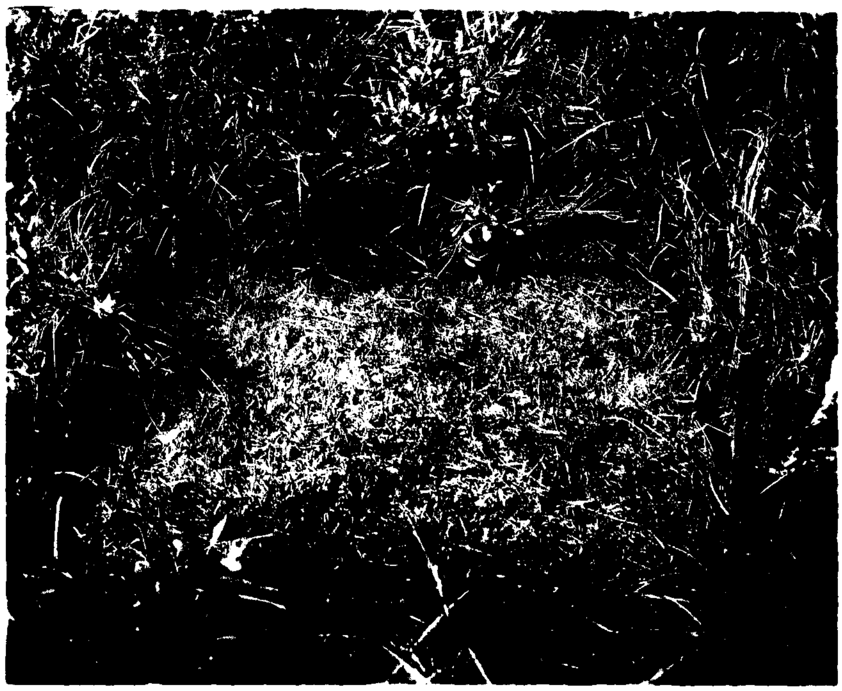
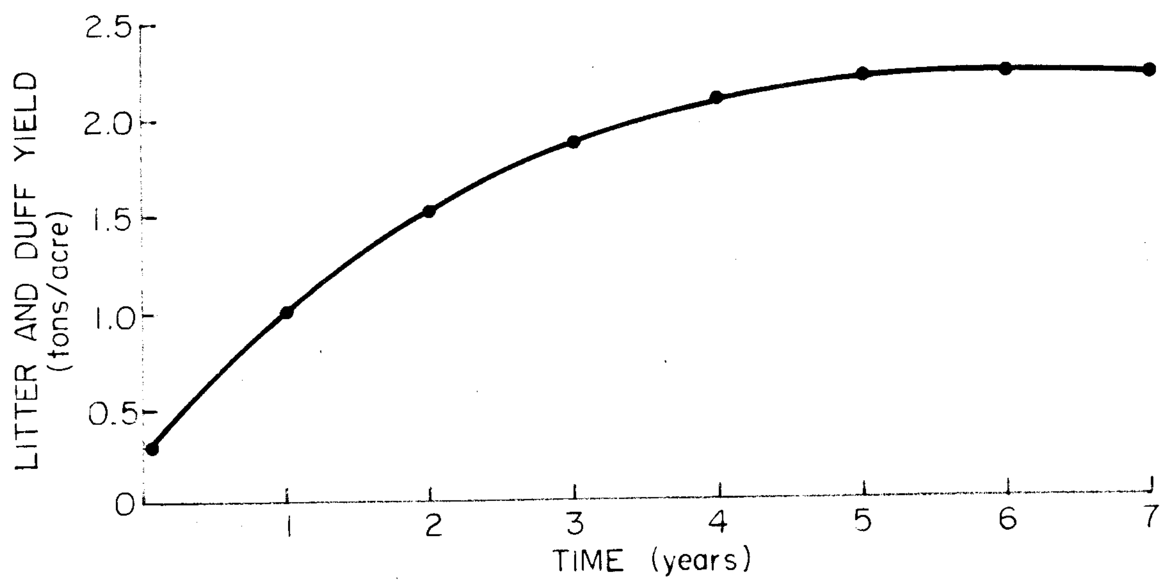


Figure 25. Accumulation of litter and duff on Hayden prairie after burning treatments. The points for years 4, 5, 6, and 7 are computed values as described in text.


LITTER AND DUFF YIELD
(tons/acre)
2.5
2.0
1.5
1.0
0.5
0
1
2
3
4
5
6
7
TIME (years)

DISCUSSION

The establishment of an effective prairie management program requires an understanding of the direct effects of a management practice on the individual species and on the prairie community, as well as an understanding of the indirect effects on the vegetation through the alteration of soil, microclimate, and other factors of the environment. The reaction of the vegetation to these direct and indirect effects of management practices depends to a large extent on the situation existing at the time of initiation of the management program. The location of the area as to soils and climate is an important consideration in the evaluation of the status of prairie development.

Prior to the purchase of the Hayden prairie by the State Conservation Commission in 1945, the prairie had been mowed for hay and intermittently pastured by cattle. The fact that certain grasses, not native to the prairie, occur scattered throughout the tract would indicate that cattle had been run on the area while under feed (2). These grasses are somewhat suppressed and of rather low vigor, but their presence throughout the tract offers a threat of permanent invasion in event of reduced vigor of the native vegetation. After its purchase in 1945, the Hayden prairie was placed under complete protection to allow the vegetation to recover from the previous excessive mowing and grazing until March, 1954, when the first burning experiment was conducted. The decision to employ burning as a management practice was based on the results of previous studies (2, 72) which indicated that recovery of the Hayden prairie had passed its highest rate by 1953, chiefly because of the accumulation of a large quantity of litter and duff that exceeded the annual production of vegetation.

The general conditions for plant growth become progressively more favorable from the western border of the prairie association to its eastern extremities. Thus, although conditions in the western portion of the prairie region may produce no more than the requisite quantity of aboveground organic material for adequate prairie maintenance, the lush vegetative growth of prairie in northeastern Iowa would result in excessive accumulation of litter and mulch under complete protection.

The most evident effect of burning was the earlier spring growth of vegetation on burned areas compared to nearby unburned areas. In the spring of 1955 initiation of vegetative growth on the various burning treatments was earliest on areas burned in both 1954 and 1955 and progressively later on areas burned in 1955, areas burned in 1954, and unburned areas. The difference in time from earliest initiation of plant growth to the latest initiation was two to three weeks. Similar results were obtained in 1956. Because of the earlier initiation of vegetative growth on burned areas and the faster rate of development throughout April, May, and June, the plants on the burned areas reached maturity at an earlier date (Figures 14 and 15).

The more rapid rate of growth of the vegetation on burned compared to unburned areas is also exemplified by the 1955 yield data from four clippings during the growing season (Figure 20, Table 16). The greatest yields from recently burned plots were obtained from the first clipping (May 30) while the greatest yields obtained from the unburned plots were from the second clipping (July 1). Thus, although there was no statistically significant difference in the total yield of the four clipping dates between burned and unburned areas, there was a significant difference in yield at various dates on burned and unburned areas.

The observed effect of earlier growth of vegetation on burned areas compared to unburned areas is in agreement with results obtained by other investigators (2, 20, 58, 119).

Soil temperature was probably the main factor causing the earlier growth on burned areas. There was a close relationship between rising soil temperature in the spring and increasing rate of growth. This relationship has been reported previously (119). From the data, it would appear that the soil temperature in the spring, as influenced by the amount of litter and duff covering the soil surface, is the most limiting factor of plant growth until about June or July when the vegetation had developed to the point where the shading effect from the vegetation was about as effective as the mulch in reducing soil temperatures. The higher soil temperatures on burned areas were most probably due to the removal of the insulating effect of the great amount of litter and duff and the consequent exposure of the very dark soil surface (Figures 3 and 4; Tables 25 and 26). It was noted that soil temperatures in the spring were highest on areas with the least amount of litter and duff and lowest on areas with the most litter and duff (Tables 25 and 26). In the spring of 1955, the amount of litter and duff was found to be lowest on the 1954, 55 burned areas and higher in order on 1955 burned, 1954 burned, and unburned areas (Figure 22, Table 24a). Since it was found that soil temperature in early spring was inversely related to the amount of litter and duff it seems reasonable that date of initiation of growth in 1955, as previously pointed out, would follow the same order from earliest on the 1954, 55 burned areas to latest on the unburned areas. This same relationship was also observed in 1956.

Air temperatures taken one inch above the ground showed a greater difference between daily maximum and daily minimum temperatures on burned than on unburned areas until June, after which there was essentially no difference (Figures 5 and 6; Tables 27 and 28). The insulating effect of the mulch accounted for the smaller differences between daily maximum and minimum temperatures on the unburned areas than on the burned areas.

Although the effect of pH and soil nutrients on rate of growth in the spring cannot be ascertained from the available data, there are important effects that might be causally related to increased growth rate (Tables 6 and 7). It was noted that on recently burned areas there was a considerably greater amount of available phosphorus in the top 0.75 inch of soil than on unburned areas. Perhaps this greater amount of available phosphorus was at least partially responsible for the increased rate of growth on burned areas.

An increase in nitrate production may also be necessary for more rapid growth. However, the results showed no significant differences in nitrate production on the various burning treatments. Since the nutrient determinations were made about two months after burning it is possible that an earlier, ephemeral effect could have been present in areas subjected to the various burning treatments. Other investigators have reported an increased rate of nitrification after burning (40). To determine if there actually was an earlier increase in nitrate production, soil samples should be taken immediately after burning and at weekly intervals or less thereafter for at least two months.

There was a slight increase in pH on burned areas, but it is doubtful if this would have any direct effect on the rate of growth. However, pH might have an effect on availability of certain nutrients and on the microbiological population of the soil, which in turn could have an effect on growth of the plants.

Exchangeable potassium apparently had no effect on the increased growth rate since it was found to be present in large amounts on all burned and unburned areas. Potassium is readily leached from dead vegetative material so it would not be expected that burning would have any great effect of releasing large amounts of potassium into the soil.

There was apparently no relationship between the growth rate in the spring and total soil organic matter in the top six inches of soil, or the percentage pore space at depths of 0-1.5 inches and 3-4.5 inches (Tables 4, 8, and 10).

Available soil water did not seem to be a factor effecting increased rate of growth in the spring; in fact there was apparently adequate soil moisture for plant growth during the entire growing seasons of 1955 and 1956 (Figures 8 and 9; Tables 30, 31, 32, and 33). This is in accord with Thornthwaite (98), who classified the area as having adequate moisture at all seasons. The available soil water was depleted more rapidly in burned than in unburned areas because of the increased transpiration from the earlier development of the vegetation and a higher rate of evaporation from the soil surface caused by the higher soil temperatures and increased exposure.

In addition to the earlier development of both grasses and forbs on burned compared to unburned areas, there was also a greater number of native prairie plants that flowered and a greater height of flowering stalks on burned areas compared to unburned areas (Figures 8, 14, and 15; Tables 12, 13, 14, and 15). The greater height and number of the various colored flowers of the broadleaf plants and the greater height and number of seedstalks of the native grasses lent a sharp contrast to the appearances of the burned and unburned areas. It was also noted that the number of seedstalks of bluegrass decreased with frequency and severity of burning.

Plant counts taken during 1955, and frequence x abundance measurements of seedstalks taken during 1956, showed a great increase in the number of forbs that flowered and the number of native grasses that produced seedstalks on recently burned areas. However, it was noted that by the second growing season after burning, there was a marked reduction in the number of forbs that produced flowers and in seedstalks production of the native grasses compared to that on recently burned areas (Table 12). By the third growing season after burning the aspect of the areas closely approached that of the unburned areas.

Plants on the burned areas had a considerably smaller proportion of leaves to seedstalks than plants on the unburned areas (Table 15, Figure 18). There were also more viable seeds per plant from the dominant grasses on the burned areas compared to the unburned areas. Canada wild rye proved to be an exception in that there was essentially no difference in height of plants, number of seedstalks, or relative proportions of various plant parts between plants from burned and unburned areas.

The increase of seedstalk heights and numbers has been reported by other investigators (2, 19, 28, 31). Curtis and Partch (28) reported a six-fold increase in seedstalks and a 60 per cent increase in height of seedstalks on planted stands of big bluestem as a result of burning. They attributed most of this increase to the removal of large quantities of litter and duff by the fire and only a very small increase from the addition of ash. It is very likely that the increased rate of growth in the spring caused by the removal of litter and duff could have certain physiological effects on the plants which would cause increased flowering. The greater amount of vegetative growth of the earlier growing plants may allow the plants to produce more carbohydrates and this greater supply of carbohydrates could possibly induce the differentiation and growth of flowerstalks. In this regard, it is interesting to note that there was a marked increase in number of seedstalks in 1956 on an area that was burned in the spring of 1955 and mowed for hay the fall of the same year, compared to an area that was burned in the spring of 1955 and not mowed. It was also noted that flowerstalk production was greatest on areas with the earliest vegetative growth, progressively less as the earliness of growth became less, and least on unburned areas that began growth latest in the spring. However, since other factors such as pH and available phosphorus were also greater on areas that produced the highest number of seedstalks and progressively less as the seedstalk production became less, it can not be determined from these results how much each factor contributed to the production of seedstalks.

Kentucky bluegrass reacted differently to burning than did the native grasses, in that the number of seedstalks decreased after early spring burning. In fact, on areas burned for three consecutive years, the frequence percentage of seedstalks decreased from 100 to 30 (Table 12). Curtis and Partch (27) noted a reduction of the bluegrass population as a result of early spring burning. They accounted for this on the basis that bluegrass started growth early in the spring and suffered damage because of the high temperature of the fire, whereas most native grasses were still in a state of dormancy and suffered no damage. The fact that bluegrass normally begins growth at cooler temperatures may also explain why it was able to grow well and produce seedstalks under the heavy mulch where the rate of growth of most native grasses was slowed down.

The amount of available phosphorus in the top 0.75 inch of soil was found to be low on all areas. However, compared to the unburned areas, there was an increase of available phosphorus of 12 times in the 1956 burned area, 6 times in the 1954, 55, 56 burned and 1954, 55 burned areas, and 2 times in the 1954 burned and 1955 burned areas. Since the amount of available phosphorus was very low on all areas, an increase such as the above mentioned could have an important effect on flowerstalk production. The results also point out that available phosphorus is not leached very readily.

Although no differences were found in nitrate nitrogen production after the various burning treatments, there could have been an earlier ephemeral effect that was not detectable when the measurements were made two months after the date of burning. Since nitrate production was low on all areas measured, any increase in nitrate could have had an important effect on growth of plants. Others have reported increased rate of nitrification after burning (40).

Exchangeable potassium probably had no effect on increased flowerstalk production since it was high on all areas and apparently not influenced by any burning treatments (Table 6).

The pH in the top 0.75 inch of soil increased slightly as a result of burning (Table 6). However, it is unlikely this slight increase could have an important effect on increasing flowerstalk production. Since there was no appreciable difference in pH between unburned areas and areas burned one or two years before and not the current year, it could be assumed that the factor causing the increase in pH was readily leached from the topsoil.

There was apparently no effect of total organic matter in the top six inches of soil on increased flowerstalk production, since there was no significant difference in amount of soil organic matter in the various burning treatments (Tables 8 and 10). Volume weight and pore space percentages were also not affected by the various burning treatments, therefore it is assumed that these factors had no effect on increased flowerstalk production (Table 4). Available soil moisture apparently did not increase flowerstalk production since there was adequate soil moisture for plant growth during the entire growing season on all areas (Figures 8 and 9; Tables 30 and 31).

In light of the results of this study, it is believed that additional burning experiments should be conducted to make a more exact evaluation of the effects of removal of litter and duff and the addition of ash as a result of burning, in the increase of number and heights of seedstalks of native prairie grasses.

The present studies indicate that occasional burning of native prairie in Iowa has no apparent deleterious effects on the vegetation or soil. In fact, when the quantity of accumulated litter and duff approaches that of the annual yield of the vegetation, its removal by burning has beneficial effects such as increased flowering of forbs, increased seedstalk production of native grasses, and a decrease in bluegrass. If burning is applied, it is recommended to use late winter or early spring burning so as to take advantage of the effect of litter in catching and holding the winter snows. Late spring burning might have an injurious effect on the vegetation.

Yield data from 1955 and 1956 clipping studies showed no statistically significant differences in total yields from burned and unburned areas, although in general, slightly greater yields were obtained from burned areas (Figures 20 and 21; Tables 16 and 19). Clipping the vegetation 1 to 2 inches above ground four times during the growing season (at about 30-day intervals) reduced yields compared to clipping at the end of the growing season. Frequent clipping for the second consecutive year caused a considerable reduction in yields while clipping at the end of the growing season for the second year resulted in only a slight reduction in yields. Yields from 1956 clipping data showed that greatest yields were obtained from plots clipped at the end of the growing season for the first year, followed closely by the yields from plots clipped at the end of the growing season for two consecutive years. Plots clipped four times during the growing season for the first year yielded considerably less than plots clipped at the end of growing season for two consecutive years. The lowest yields were obtained from plots clipped four times during the growing season for two consecutive years.

The injurious effects on the vegetation under frequent clipping is probably related to reduction of leaf area and subsequent decrease in production of carbohydrates. Initial growth of herbage in the spring is made at the expense of carbohydrates stored in the basal organs of the plant the preceding season. Not all stored food is used in normal, early growth of perennial grass. However, if this new growth is removed by early clipping or grazing, there results a decrease in reserve food. A second close clipping further depletes the reserves, and continued close clipping throughout the growing season can either seriously injure the plant or cause its eventual death. In this weakened condition the plant may not be able to compete successfully with other plants such as bluegrass, redtop, or timothy, which are more resistant to mowing or grazing (9, 14, 69, 71). As a result of a decrease in top growth from frequent removal by mowing or grazing, there is also reduction in root growth of the plant (16, 18, 41, 44). In fact, Branson (16) reported that frequent clipping had a more pronounced effect on root production than on shoots. This decrease in root production is manifest in both reduced quantity and depth of penetration.

The results of these clipping studies would indicate that the best method of removal of the vegetation so as to prevent the deleterious effects of excessive accumulation of aboveground organic material, and yet not injure the native vegetation, would be to mow at the end of the growing season after the plants have made seed. This method would be in keeping with the desired objective of the perpetuation of the native prairie.

Grazing experiments were not conducted since the practice is considered too severe under plant growth conditions favorable to the development of mesic prairie in Iowa. Grazing would result in compaction of soil and selective and severe use of key prairie grasses, which would favor competing bluegrass, timothy, and redtop and cause a reduction of native prairie plants (2, 27). The presence of many suppressed bluegrass plants in the Hayden prairie at the present time could pose a serious threat to the native grasses under improper management. Thus, grazing would definitely not be suggested as a management practice on the Hayden prairie.

Although complete protection of the Hayden prairie was necessary to allow the recovery of the vegetation from past excessive mowing and grazing, it could not be recommended as a long-time management practice. Results showed that if complete protection were afforded under the mesic conditions of the Hayden prairie area, it would take only about four to six years after burning for litter and duff to accumulate to the extent that it would equal or exceed the annual yield of vegetation (Figure 25). However, complete protection for a year or two may be necessary or advantageous at various times.

It would appear that any long-time management program should be a flexible one, capable of adjustment when necessary. At present, mowing with heavy commercial equipment in early autumn, after seed has been formed, appears to be feasible. Under this practice, the lowland portion of the prairie could usually be mowed two to three weeks earlier than the upland prairie. A suitable plan might be to mow approximately two-thirds of the prairie every year, leaving certain critical areas unmowed. However, in mowing the prairie, care should be taken not to disturb the area excessively in the harvesting operation with heavy tractors and trucks. Another suggested management program might be to burn approximately one-fourth of the area every year on a rotational basis, leaving three-fourths unburned. A plan based on mowing as required with occasional burning to promote seed production of native species would be most desirable. Under any management program, it is suggested that at least one-third of the area be left undisturbed every year in order to prevent any damage to the vegetation which might possibly occur with too frequent application of a management practice and also to disturb the wildlife of the areas as little as possible. In this regard, the prairie should be kept under constant surveillance so that the management program could be altered in event of any adverse effects on either the native flora or fauna.

SUMMARY

1. The immediate and cumulative effects of different management practices such as complete protection, burning, and mowing were studied on the vegetation and soil of the mesic Hayden prairie in northeastern Iowa.

2. The Hayden prairie was under complete protection from 1945, when it was purchased by the Iowa State Conservation Commission, to March, 1954, the date of the first burning experiment. It was determined that the prairie had passed its highest rate of recovery from past overuse by 1953, chiefly because of the accumulation of a large quantity of litter and duff that exceeded the annual yield of vegetation.

3. Plants on recently burned areas began growth two to three weeks earlier in the spring than plants on unburned areas. Soil temperature as influenced by the amount of litter and duff covering the soil surface seemed to be the most limiting factor of plant growth until June or July.

4. The more rapid rate of growth on burned areas is manifest by the 1955 yield data from plots clipped at four different dates during the growing season. The greatest yields obtained from burned plots were from the first clipping (May 30) while the greatest yields obtained from unburned plots were from the second clipping (July 1).

5. Plants on burned areas reached various stages of maturity at an earlier date than plants on the unburned areas.

6. The frequence x abundance of seedstalks of native grasses increased with burning and that of bluegrass and other invading grasses decreased with burning.

7. There were a greater number and height of flowerstalks of forbs and native grasses on burned than on unburned areas. The number of seedstalks of bluegrass decreased with frequency and severity of burning.

8. By the third growing season after burning, the number and height of flowerstalks of forbs and native grasses were about the same as on the unburned areas.

9. The dominant native grasses in the burned areas had a considerably smaller proportion of leaves to seedstalks than on unburned areas except for Canada wild rye which showed no differences.

10. The greater number and height of flowerstalks on burned areas may have been caused by the earlier growth of plants with the consequent increase in stored carbohydrates, and/or increased availability of certain soil nutrients.

11. The soil temperature was considerably higher at all depths in the burned than in the unburned areas until July or August, after which there was essentially no difference. The

higher soil temperatures on burned areas were probably due to removal of the insulating effect of the great amount of litter and duff and the darker, exposed soil surface.

12. The difference between maximum and minimum air temperatures at one inch above the ground was greater on burned than unburned areas until June, after which date there was essentially no difference.

13. The available soil water was depleted more rapidly in burned than in unburned areas because of the faster transpiration from the earlier development of the vegetation and also faster evaporation from the soil surface caused by the higher soil temperatures. There was adequate soil moisture for plant growth during the entire growing season for both 1955 and 1956.

14. There was no difference in soil volume weight or percentage pore space in burned and unburned areas.

15. There was a slight increase in the pH of the surface 0.75 inch of soil in recently burned areas.

16. Although available phosphorus as measured in 1956 was low on all areas compared to the unburned areas, there was an increase of available phosphorus of 12 times in the 1956 burned areas, 6 times in the 1954, 55, 56 burned and 1954, 55 burned areas, and 2 times in the 1954 burned and 1955 burned

areas.

17. There was essentially no difference in exchangeable potassium or nitrate production in the top 0.75 inch of soil from burned and unburned areas.

18. Organic matter determination showed that burning for as much as three consecutive years had no effect on total organic matter in the top six inches of soil.

19. There was no significant difference in total yields from burned and unburned areas.

20. Clipping four times during the growing season reduced yields compared to clipping at the end of the growing season. Frequent clipping for the second consecutive year caused considerable reductions in yields while clipping at the end of the growing season for the second year resulted in only very slight reductions of yields.

21. Complete protection of the mesic Hayden prairie for four to six years after burning would result in an accumulation of litter and duff which would equal or exceed the annual yield of vegetation.

22. Grazing is considered too severe a practice on native prairie in eastern Iowa.

23. A suitable management plan which would be in keeping

with the perpetuation of the native vegetation would be to mow, in early autumn, approximately two-thirds of the areas every year, leaving certain critical areas unmowed. A management program based on mowing as required with occasional burning to promote seed production of native species would be more suitable.

24. The prairie should be kept under constant surveillance so that the management program could be altered in the event of any adverse effects on either the native flora or fauna.

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APPENDIX

Table 25. Soil temperature (^{o}F) at three depths in burned and unburned areas, 1955[a]

Date	Burned 1954,55			Unburned		
	Depth in inches			Depth in inches		
	½	2	5	½	2	5
April 2	54	50	43	52	39	38
April 22	50	48	45	48	47	41
May 13	66	56	52	57	52	47
May 30	75	63	57	66	57	52
June 19	75	68	64	70	66	63
July 4	79	75	72	77	73	70
July 17	73	68	66	72	66	64
August 5	75	73	70	77	75	70
August 22	77	72	68	75	72	68
September 2	79	72	70	68	70	68
September 8	72	66	63	72	66	63

[a]Temperatures taken between 1:00 and 2:00 P.M. on date indicated.

Table 26. Soil temperatures (°F) at three depths in burned and unburned areas, 1956[a]

Date	Burned 1954,55,56			Unburned		
	Depth in inches			Depth in inches		
	½	2	5	½	2	5
April 13	56	50	43	52	48	43
May 19	61	57	56	56	52	50
June 16	86	77	70	77	72	66
June 30	84	79	72	73	68	64
July 13	86	79	73	80	75	70
August 4	86	79	73	84	77	73
August 17	77	73	70	77	72	70
September 2	73	70	64	73	70	64
September 22	68	66	61	70	66	63

[a]Temperatures taken between 1:00 and 2:00 P.M. on date indicated.

Table 27. Maximum and minimum temperatures (^{o}F) on burned and unburned areas, 1955[a]

Date	Burned 1954,55		Unburned	
	Maximum	Minimum	Maximum	Minimum
April 2	84	29	83	31
April 22	75	28	63	34
May 13	96	36	90	40
May 30	97	39	88	38
June 19	99	50	90	48
July 4	110	55	108	53
July 17	114	63	107	63
August 5	115	55	110	52
August 22	105	45	104	44
September 2	101	40	96	38
September 8	99	36	88	33

[a]Temperatures taken at approximately one inch above ground between 1:00 and 2:00 P.M. on date indicated.

Table 28. Maximum and minimum temperatures (^{o}F) on burned and unburned areas, 1956[a]

Date	Burned 1954,55,56		Unburned	
	Maximum	Minimum	Maximum	Minimum
April 13	76	27	68	31
May 19	88	35	74	45
June 16	100	63	89	59
June 30	98	44	92	41
July 13	105	45	101	44
August 4	106	41	101	40
August 17	110	36	105	35
September 2	98	35	94	35
September 22	88	30	84	28

[a]Temperatures taken at approximately one inch above ground between 1:00 and 2:00 P.M. on date indicated.

Table 29. Average monthly temperatures and total monthly precipitation for 1954, 1955, and 1956 at Saratoga and long-time averages at Cresco weather station[a]

Month	1954		1955		1956		Long-time average	
	Temp.	Ppt.	Temp.	Ppt.	Temp.	Ppt.	Temp.	Ppt.
January	15.8	0.63	15.0	0.04	11.6	0.18	14.0	1.12
February	32.4	0.27	16.2	0.31	13.9	0.12	17.5	1.05
March	28.5	1.32	27.8	1.08	26.2	2.77	30.0	1.85
April	49.7	4.98	51.8	3.59	40.9	2.65	45.5	2.43
May	51.5	5.18	60.2	3.86	58.9	4.70	57.5	4.40
June	68.0	7.66	63.8	3.39	72.5	2.88	66.5	4.70
July	71.6	3.32	75.7	1.64	6.66	6.12	71.5	3.81
August	66.3	6.63	73.3	0.54	68.4	2.17	69.5	3.36
September	60.3	3.26	61.8	2.77	57.5	2.56	60.1	3.64
October	48.3	3.90	50.1	1.76	56.1	2.00	48.6	2.45
November	37.6	0.33	30.1	0.03	31.8	1.39	34.6	1.85
December	22.1	0.69	16.0	1.10	22.5	0.13	20.1	1.24
Total		38.17		20.11		27.67		31.90
Mean	40.0		45.2		43.9		44.5	

[a]The Saratoga weather station is located four miles south of the Hayden prairie and the Cresco weather station nine miles east of the Saratoga station.

Table 30. Available soil moisture from burned and unburned areas computed in inches of water in a four foot profile, 1955[a]

Treatment	Date						
	April 22	May 12	June 18	July 16	Aug. 6	Sept. 2	Nov. 12
burned 1954, 55	12.39	11.97	8.04	5.48	2.60	1.85	3.25
burned 1955	14.72	13.55	9.39	6.16	3.23	2.16	5.09
burned 1954	12.43	13.17	9.16	5.73	3.11	2.21	2.19
unburned	14.36	14.18	9.88	7.24	4.02	2.54	2.88

[a]These values were calculated from average values of per cent moisture by weight. Each value was obtained by subtracting 7.70 inches of unavailable water from the total amount of water in the four foot soil profile.

Table 31. Available soil moisture from burned and unburned areas computed in inches of water in a four foot profile, 1956[a]

Treatment	Date							
	April 13	May 15	June 16	June 30	July 13	Aug. 5	Sept. 2	Sept. 22
burned 1954, 55,56	9.45	8.83	4.00	3.82	4.42	5.73	3.42	4.31
burned 1954, 55	8.95	9.58	7.42	6.74	6.32	7.64	4.78	5.51
burned 1954	9.31	8.94	8.28	6.30	6.51	7.98	5.29	5.22
unburned	8.18	9.56	8.58	7.37	7.10	8.46	5.53	5.29

[a]These values were calculated from average values of per cent moisture by weight. Each value was obtained by subtracting 7.70 inches of unavailable water from the total amount of water in the four foot soil profile.

Table 32. Soil water content in percentage of dry soil weight and in inches of water for various depths and treatments as determined in 1955[a]

Treatment	Depth in inches	April 22		May 12		June 18		July 16		Aug. 6		Sept. 2		Nov. 12	
		% by wt.[b]	in. H_2O[c]	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O
burned 1954,55	0-6	53	2.52	49	2.33	40	1.90	27	1.82	19	0.90	16	0.76	37	1.75
	6-12	43	2.65	39	2.41	39	2.41	24	1.48	18	1.11	15	0.89	27	1.67
	12-24	33	4.80	33	4.80	28	4.07	22	3.19	15	2.18	14	1.96	17	2.47
	24-36	25	4.42	25	4.42	22	3.89	19	3.35	15	2.64	14	2.47	12	2.11
	36-48	28	5.70	28	5.70	20	4.08	19	3.79	17	3.47	17	3.47	15	2.95
burned 1955	0-6	56	2.66	57	2.70	48	2.28	29	1.43	21	1.00	17	0.81	41	1.92
	6-12	51	3.15	46	2.84	40	2.47	26	1.61	19	1.17	16	0.95	34	2.10
	12-24	37	5.38	38	5.52	31	4.50	25	3.63	17	2.47	14	1.96	18	2.54
	24-36	29	5.11	30	5.29	19	3.35	20	3.53	16	3.82	15	2.64	15	2.64
	36-48	30	6.12	24	4.90	22	4.49	18	3.67	17	3.47	18	3.67	18	3.67
burned 1954	0-6	53	2.52	56	2.70	54	2.56	29	1.43	19	0.90	18	0.85	33	1.57
	6-12	41	2.53	42	2.59	37	2.28	26	1.61	18	1.11	15	0.92	22	1.36
	12-24	33	4.80	34	4.93	29	4.21	22	3.19	16	2.33	14	2.03	14	2.03

[a]These values represent means for three replicates.

[b]The unavailable water for each depth increment on % by weight basis is: 0-6 in., 17.2; 6-12 in., 14.3; 12-24 in., 12.4; 24-36 in., 11.2; 36-48 in., 10.9.

[c]The unavailable water in inches of water for each depth increment is: 0-6 in., 0.82; 6-12 in., 0.88; 12-24 in., 1.80; 24-36 in., 1.98; 36-48 in., 2.22.

Table 32, continued

Treatment	Depth in inches	April 22		May		June 18		July 16		Aug. 6		Sept. 2		Nov. 12	
		% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O
	24-36	26	4.58	28	4.94	20	3.53	19	3.35	17	2.98	15	2.64	14	2.47
	36-48	28	5.70	28	5.70	21	4.34	19	3.79	17	3.47	17	3.47	13	2.54
	0-6	47	2.23	51	2.42	51	2.42	32	1.52	20	0.95	21	1.00	32	1.52
	6-12	43	2.65	40	2.47	41	2.53	30	1.85	19	1.17	16	0.95	24	1.48
unburned	12-24	34	4.93	36	5.22	32	4.66	26	3.78	19	2.76	15	2.18	16	2.33
	24-36	29	5.11	31	5.46	22	3.89	21	3.71	18	3.18	15	2.64	14	2.47
	36-48	35	7.14	31	6.31	21	4.94	20	4.08	18	3.67	17	3.47	14	2.86

Table 33. Soil water content in percentage of dry soil weight and in inches of water for various depths and treatments as determined in 1956[a]

Treat-	Depth in inches	Date															
		April 13		May 15		June 16		June 30		July 13		Aug. 5		Sept. 2		Sept. 22	
		% by wt.[b]	in. H_2O[c]	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O
	0-6	42	1.98	48	2.29	24	1.55	25	1.26	24	1.14	38	1.79	30	1.45	35	1.66
burned	6-12	35	2.18	41	2.55	26	1.60	23	1.42	23	1.42	33	2.06	25	1.53	27	1.66
1954,	12-24	30	4.37	30	4.37	22	3.17	18	2.60	22	3.17	24	3.52	18	2.60	20	2.93
55,56	24-36	24	4.28	24	4.28	18	3.18	16	2.77	16	2.77	17	2.96	14	2.47	15	2.64
	36-48	21	4.34	19	3.79	18	3.67	17	3.47	17	3.47	15	2.95	15	2.95	16	3.24
	0-6	45	2.14	43	2.04	34	1.63	35	1.66	31	1.48	40	1.90	32	1.53	35	1.66
burned	6-12	42	2.61	39	2.42	32	2.00	33	2.03	28	1.75	36	2.23	27	1.64	29	1.81
1954,	12-24	27	3.89	31	4.54	26	3.77	26	3.77	24	3.52	29	4.22	23	3.30	22	3.17
55	24-36	23	4.01	24	4.28	21	3.71	19	3.35	19	3.35	18	3.18	15	2.64	18	3.18
	36-48	20	4.08	20	4.08	20	4.08	18	3.67	19	3.79	18	3.67	16	3.24	17	3.47
	0-6	42	1.99	45	2.14	37	1.74	35	1.66	33	1.55	39	1.84	32	1.51	35	1.66
burned	6-12	36	2.23	36	2.23	32	2.00	30	1.85	28	1.74	35	2.18	25	1.53	29	1.78
1954	12-24	28	4.10	29	4.20	28	4.10	22	3.17	25	3.67	29	4.22	21.	3.02	22	3.17

[a]These values represent means for three replicates.

[b]The unavailable water for each depth increment on % by weight basis is: 0-6 in., 17.2; 6-12 in., 14.3; 12-24 in., 12.4; 24-36 in., 11.2; 36-48 in., 10.9.

[c]The unavailable water in inches of water for each depth increment is: 0-6 in., 0.82; 6-12 in., 0.88; 12-24 in., 1.80; 24-36 in., 1.98; 36-48 in., 2.22.

Table 33, continued

Treat-	Depth in inches	April 13		May 15		June 16		June 30		July 13		Aug. 5		Sept. 2		Sept. 22	
		% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O	% by wt.	in. H_2O
	24-36	24	4.28	23	4.01	22	3.89	20	3.53	20	3.53	20	3.53	19	3.35	18	3.18
	36-48	22	4.49	20	4.08	21	4.34	20	4.08	19	3.79	20	4.08	18	3.67	16	3.14
	0-6	43	2.02	42	1.99	38	1.81	35	1.66	33	1.55	39	1.84	31	1.48	31	1.48
	6-12	34	2.08	40	2.49	33	2.03	31	1.93	30	1.85	38	2.33	25	1.53	28	1.72
unburned	12-24	27	3.89	32	4.60	30	4.37	27	3.89	26	3.80	31	4.54	21	3.11	23	3.30
	24-36	22	3.89	25	4.42	24	4.28	20	3.53	21	3.71	20	3.53	19	3.35	17	2.96
	36-48	20	4.08	19	3.79	19	3.79	20	4.08	19	3.79	20	4.08	19	3.79	17	3.47

Table 34. Analysis of variance of soil moisture data, 1955 (Table 32)

Source of variance	Degrees of freedom	Mean square
location	2	37.6[a]
burning treatment	3	135.0[b]
date	6	4,950.0[a]
depth	4	4,055.0[a]
burn x date	18	29.2[a]
burn x depth	12	20.3
date x depth	24	277.0[a]

[a]Significant at the 1% level.

[b]Significant at the 5% level.

Table 35. Analysis of variance of soil moisture data, 1956 (Table 33)

Source of variance	Degrees of freedom	Mean square
locations	1	13.0[a]
burning treatments	3	166.5[b]
dates	7	443.8[b]
depths	4	3,662.3[b]
burn x date	21	21.1[b]
burn x depth	12	6.3
date x depth	28	38.2[b]

[a]Significant at the 5% level.

[b]Significant at the 1% level.